[redacted]

~~RESTRICTED~~

M I N U T E S A N D P R O C E E D I N G S

of the eighteenth meeting of the

ARMY - NAVY - NRC VISION COMMITTEE

January 14-15, 1947

Aero Medical Laboratory
Wright Field, Dayton, Ohio

~~RESTRICTED~~

[redacted]

U. S. Armed Forces - NRC Vision
" Committee

~~RESTRICTED~~

ARMY-NAVY-NRC VISION COMMITTEE

Chairman: Captain C.W. Shilling (MC) USN
Deputy Chairman: Major E.A. Pinson, USA
Executive Secretary: Donald Marquis
Technical Aide: H. Richard Blackwell

EXECUTIVE COMMITTEE

Detlev W. Bronk
Comdr. H.G. Dyke, USNR
Selig Hecht
Edwin R. Henry
Col. E.N. Kirsten, USA
Urner Liddel
Walter R. Miles

MEMBERSHIP AND DISTRIBUTION LIST

	Members	Alternates
AAF	Major E.A. Pinson Aero Medical Laboratory TSEAL-3C, Area "B" Wright Field, Dayton, Ohio	Dr. Paul M. Fitts Aero Medical Laboratory Psychology Branch Wright Field, Dayton, Ohio
AAF Randolph Field	Major Herman S. Wigodsky, MC Director of Research AAF School of Aviation Medicine Randolph Field, Texas	
AAF	Col. Ben G. Holzman HQ, Air Weather Service Army Air Forces, Wash. 25, D.C.	
AGF	Col. William Alexander Chief, F.A. Branch Development Section HQ, Army Ground Forces, Wash. D.C.	Col. J.C. Welborn Infantry Branch HQ, Army Ground Forces Washington, D.C.
	Col. Bryan Evans HQ, Army Ground Forces Room 4E821, Pentagon Building Washington 25, D.C.	
AGO	Dr. Edwin R. Henry Personnel Research Section, AGO 270 Madison Avenue New York 16, N.Y.	Dr. Horace H. Corbin Personnel Research Section, AGO 270 Madison Avenue New York 16, N.Y.

[redacted]

	Members	Alternates
Asst. Chief Staff G-1	Col. A.T. McAnsh Office, Asst. Chief of Staff G-1 Rm 2C-922, The Pentagon Washington 25, D.C.	Major Gordon L. Barclay Personnel & Administration Div. War Department General Staff Washington 25, D.C.
Engrs	Mr. Noel W. Scott Engineer Board Ft. Belvoir, Va.	
Ord	Mr. John E. Darr Room 4C-430, Pentagon Bldg. Washington 25, D.C.	
QMG	Col. Jack E. Finks Office of the QM General Washington 25, D.C.	Mr. John C. Rich R & D Branch Office of the Quartermaster Gen. Washington 25, D.C.
Signal Corps	Mr. N.D. Stulman Special Projects Branch Engineer & Technical Service Office, Chief Signal Officer Room 3C-278, The Pentagon Washington, D.C.	
Research & Dev'mt Division	Col. E.N. Kirsten Chief, Fire Control Design Div. Ordnance Department Frankford Arsenal, Philadelphia, Pa.	
SG	Lt. Col. Clark B. Meador Medical Corps Director, Development Div. Office of the Surgeon General War Department, Wash. D.C.	Lt. Col. M. Elliot Randolph Office of the Surgeon General War Department Washington 25, D.C.
NAVY		
BuAer	Lt. Comdr. W.L. Lovejoy BuAer, Navy Dept. Washington 25, D.C.	Mr. William R. Sidle BuAer, Navy Dept. Washington 25, D.C.
BuMed	Capt. J.H. Korb (MC) USN Bureau of Medicine & Surgery Navy Department Washington 25, D.C.	

NAVY	Members	Alternates
BuOrd	Mr. M. Goldberg Bureau of Ordnance Navy Department Washington 25, D.C.	
BuPers	Capt. F.B.C. Martin, USN Bureau of Naval Personnel Navy Department Washington 25, D.C.	Dr. Everett G. Brundage Bureau of Naval Personnel Navy Department Washington 25, D.C.
BuShips	Capt. H.T. Chase Bureau of Ships Section 624, Navy Dept. Washington 25, D.C.	Comdr. Dayton R.E. Brown Bureau of Ships Code 342, Navy Department Washington 25, D.C.
	Mr. C.S. Woodside Section 921 Bureau of Ships Navy Dept., Washington, D.C.	Mr. L. Dunkleman Section 921 Bureau of Ships Navy Dept., Washington, D.C.
DCNO (Air)	Capt. Oran W. Chenault DCNO (Air), Navy Dept. Washington 25, D.C.	
ONR	Dr. Urner Liddel Planning Branch Office of Naval Research Navy Department, Wash. D.C.	
	Comdr. H.G. Dyke Office of Naval Research Navy Department Washington 25, D.C.	
	Capt. Arthur J. Vorwald Medical Sciences Branch Office of Naval Research Navy Department Washington 25, D.C.	Dr. Henry A. Imus Head, Psychophysiology Section Medical Sciences Branch Office of Naval Research Washington 25, D.C.
NRL	Dr. E.O. Hulburt Naval Research Laboratory Anacostia, Washington, D.C.	Dr. Richard Tousey Naval Research Laboratory Anacostia, Washington, D.C.
Sub Base	Captain C.W. Shilling (MC) USN Medical Research Department U.S. Submarine Base New London, Connecticut	
Marine Corps	Maj. Walter L. Eddy, Jr. Room 2130, Division P & P Headquarters, USMC Washington, 25, D.C.	

NATIONAL RESEARCH COUNCIL MEMBERS

Dr. Stanley S. Ballard
Head, Department of Physics
Tufts College
Medford, Massachusetts

Dr. Conrad Berens
Ophthalmological Foundation, Inc.
35 E. 70th St.
New York, N.Y.

Dr. Detlev W. Bronk
Johnson Foundation for Med. Physics
School of Medicine, U. of Pa.
Philadelphia, Pa.

Dr. George M. Byram
Southeastern Forest Experiment Sta.
Federal Building
Asheville, North Carolina

Dr. Theodore Dunham
Room 22-241, Radiation Laboratory
Mass. Inst. of Technology
Cambridge, Mass.

Dr. Clarence H. Graham
Dept of Psychology
Columbia University
New York, New York

Dr. Arthur C. Hardy
Dept. of Physics
Mass. Inst. of Technology
Cambridge 39, Massachusetts

Dr. H.K. Hartline
Johnson Foundation for Med. Physics
School of Med., Univ. of Pa.
Philadelphia, Pa.

Dr. Selig Hecht
Laboratory of Biophysics
Columbia University
New York, N.Y.

Dr. Walter Miles
Yale School of Medicine
New Haven, Connecticut

Dr. Brian O'Brien
Director, Institute of Optics
University of Rochester
Rochester 7, New York

Dr. Richard G. Scobee
Dept. of Ophthalmology
Washington University
St. Louis, Missouri

Dr. Derrick T. Vail
Chairman, Dept. of Ophthalmology
Northwestern University
Chicago, Illinois

Dr. Morris S. Viteles
Dept. of Psychology
106 College Hall, Univ. of Penn.
Philadelphia, Pa.

Dr. George Wald
Biological Laboratories
Harvard University
Cambridge, Massachusetts

ASSOCIATES

Dr. Neil R. Bartlett
Department of Psychology
Johns Hopkins University
Baltimore, Maryland

Dr. Howard S. Bartley
8 W. Brainerd St.
Pensacola, Florida

ASSOCIATES

Dr, Lloyd H. Beck
Department of Psychology
Yale University
New Haven, Connecticut

Dr. F. S. Brackett
Industrial Hygiene Research Lab.
National Institute of Health
Bethesda, Maryland

Mr. F.C. Breckenridge
National Bureau of Standards
Washington, D.C.

Dr. Alphonse Chapanis
Systems Research Project
Johns Hopkins University
Baltimore 18, Maryland

Dr. Howard S. Coleman
School of Chemistry & Physics
The Pennsylvania State College
State College, Pa.

Lt. Comdr. Ellsworth B. Cook
Medical Research Department
U.S. Submarine Base
New London, Connecticut

Mr. C.A. Douglas
National Bureau of Standards
Washington, D.C.

Dr. S.Q. Duntley
Room 8-203
Mass. Institute of Technology
Cambridge, Massachusetts

Lt. Comdr. Dean Farnsworth
Medical Research Dept.
U.S. Submarine Base
New London, Connecticut

Dr. Glenn A. Fry
School of Optometry
The Ohio State University
Columbus 10, Ohio

Mr. Conrad G. Mueller
Dept. of Psychology
Columbia University
New York, New York

Dr. Irvine C. Gardner
National Bureau of Standards
Washington 25, D.C.

Dr. K.S. Gibson
National Bureau of Standards
Washington, D.C.

Mr. Louis P. Harrison
Chief, Technical Investigations Sec.
U.S. Weather Bureau
Washington, D.C.

Dr. Dean B. Judd
National Bureau of Standards
Washington, D.C.

Mr. Harry J. Keegan
Division of Photometry & Colorimetry
National Bureau of Standards
Washington, D.C.

Dr. E.S. Lamar
Operations Evaluation Group
Navy Department
Washington 25, D.C.

Commander R.H. Lee
Naval Medical Research Institute
Bethesda, Maryland

Mr. A. Lovoff
Section 921
Bureau of Ships
Navy Department, Wash. 25, D.C.

Dr. Leonard C. Mead
Head, Human Engineering Section
Special Devices Center
Office of Naval Research
Port Washington, Long Island, N.Y.

Dr. Carl W. Miller
Department of Physics
Brown University
Providence, Rhode Island

ASSOCIATES

Dr. Hans Neuberger
Division of Meteorology
Pennsylvania State College
State College, Pa.

Dr. Kenneth N. Ogle
Dartmouth Eye Institute
Hanover, New Hampshire

Lt. Harry Older
Aviation Psychology Branch
Bureau of Medicine & Surgery
Navy Department, Washington D.C.

Dr. James C. Peskin
Vision Unit
Aero Medical Laboratory
Wright Field, Dayton, Ohio

Dr. Lorrin A. Riggs
Department of Psychology
Brown University
Providence, Rhode Island

Dr. Charles Sheard
Mayo Foundation
Rochester, Minnesota

Dr. Simon Shlaer
Laboratory of Biophysics
Columbia University
New York, New York

Mr. Morris Smith
Code 660 E8, Room T4-1508
Bureau of Ships
Washington, D.C.

Dr. Jacinto Steinhardt
Operations Evaluation Group
Navy Department
Washington, 25, D.C.

Dr. John Sulzman
1831 Fifth Avenue
Troy, New York

Dr. Joseph C. Tiffin
Department of Psychology
Purdue University
Lafayette, Indiana

Dr. W.S. Verplanck
Dept. of Psychology
Indiana University
Bloomington, Indiana

Dr. Robert J. Wherry
Personnel Research Section, AGO
270 Madison Avenue
New York, 16, New York

Dr. D.J. Windenburg
The David Taylor Model Basin
Washington, D.C.

ADDITIONAL DISTRIBUTION

Director, Research Activity
Bureau of Personnel
Navy Department
Washington 25, D.C.

Mr. M.O. Watson, Air Attache
Scientific Research Liaison Office
Australian Legation
Washington, D.C.

Medical Field Research Lab.
Camp Lejeune
New River, North Carolina

Captain James R. Pahl
RE-4, BuOrd, Room 4121
Navy Department
Washington 25, D.C.

Mr. W.H. Stephens
Asst. Director, United Kingdom
Scientific Mission
1785 Massachusetts Ave., N.W.
Washington 6, D.C.

Director, Systems Research Proj.
Johns Hopkins University
Baltimore 18, Maryland

[redacted]D

ADDITIONAL DISTRIBUTION (cont'd)

Training Library
Bureau of Naval Personnel
Navy Department
Washington 25, D.C.

Captain R.C. Young
Office of Naval Research
Navy Department
844 N. Rush St., Chicago, Illinois

Dr. Alfred B. Focke
Sr. Scientific Consultant
U.S. Navy Electronics Lab.
San Diego, California

[redacted]D

ARMY-NAVY-NRC VISION COMMITTEE

Minutes of the Eighteenth Meeting

January 14-15, 1947

Aero Medical Laboratory
Wright Field, Dayton, Ohio

The following were present:

ARMY	AAF Wright Field	Major E.A. Pinson
		Dr. Paul M. Fitts
		Dr. C.E. Baer
		Mr. J.P. Callahan
		Mr. J.M. Christensen
		Mr. G.B. Fanning
		Dr. Walter F. Grether
		Mr. D.E. Hollinger
		Mr. Ben B. Johnstone
		Mr. T.P. Mountz, Jr.
		Mr. William H. Nelson
		Dr. James Peskin
		Lt. Col. C.E. Reichert
		Mr. L.P. Richmond
		Mr. Gerald C. Schutz
		Mr. H.J. Schroeder
		Mr. H.R. VanSaun
		Mr. M.J. Warrick
		Mr. J.C. Wilks
	AAF	Major A.C. Tucker, Office of the Air Surgeon, Wash, D.C.
	AGO	Dr. Edwin R. Henry
	Engrs	Mr. Noel W. Scott
	Ord	Mr. John E. Darr
	QMG	Mr. John C. Rich
NAVY	BuAer	Mr. William R. Sidle
		Lt. Harry G. Wagner (MC) USN, Aero Med. Dept., Philadelphia
	BuMed	Captain J.H. Korb
	BuOrd	Mr. Michael Goldberg

NAVY	ONR	Comdr. H. Gordon Dyke
		Dr. Henry A. Imus
		Dr. Urner Liddel
		Dr. J.W. Macmillan
	NMRI	Comdr. Richard H. Lee
		Lt. Alfred A. Schiller
	NRL	Dr. Richard Tousey
		Mr. Lloyd V. Searle
	Sub-Base	Captain C.W. Shilling
		Lt. Comdr. Ellsworth B. Cook
		Lt. Comdr. Dean Farnsworth
NRC		Dr. Stanley S. Ballard
		Dr. George M. Byram
		Dr. Richard G. Scobee
ASSOCIATES		Dr. Howard S. Bartley
		Dr. Alphonse Chapanis
		Dr. Howard S. Coleman
		Dr. Glenn A. Fry
		Dr. Irvine C. Gardner
		Dr. Leonard C. Mead
		Dr. Hans Neuberger
		Dr. Lorrin A. Riggs
		Dr. C.P. Seitz
		Dr. W.S. Veiplanck
GUESTS		Mr. C.A. Aholt
		Mr. D.L. Beane
		Dr. William C. Biel, Denison University
		Mr. Edmund E. Dudek, Purdue University
		Dr. D.G. Ellson, Indiana University
		Mr. A.J. Falkowski
		Dr. Glenn Finch
		Dr. Adelbert Ford, Lehigh University
		Mr. C.S. Franklin
		Mr. John G. Gleason, Purdue University
		Dr. Richard H. Henneman, Strategic Air Command, Andrews Field, Md.
		Dr. John G. Jenkins, University of Maryland
		Dr. William E. Kappauf, Princeton University
		Dr. John L. Kennedy, Tufts College
		Mr. R.E. Lang
		Dr. Roger B. Loucks, University of Washington
		Dr. Gordon Milne, University of Rochester
		Mr. Phillip H. Mitchell, Strategic Air Command, Andrews Field, Md.
		Mr. G.B. Schwennesen
		Mr. Robert Speight, Purdue University
		Dr. W.M. Smith, Princeton University
		Mr. R. Urmston, Indiana University
		Dr. John Volkmann, Mount Holyoke College
		Dr. A.C. Williams, Jr., University of Illinois
		Dr. S.B. Williams, Johns Hopkins University
		Dr. Donald G. Marquis
		Mr. H. Richard Blackwell

Tuesday Morning, January 14, 1947

1. The morning was devoted to a tour of Wright Field. Members and guests of the Vision Committee were invited to inspect the human centrifuge at the Aero Medical Laboratory, and were given demonstrations of radar and other electrical flight equipment. Opportunity was given for examination of the instrument panel of a B-29, and for conversation with the pilot concerning his impressions of the instrument panel.

Tuesday Afternoon

2. Captain C.W. Shilling officially opened the meeting with a few remarks to provide orientation of the special guests. He reviewed the history of the Vision Committee and outlined its activities and objectives. ---------- 1

3. Dr. Paul Fitts presented a paper entitled "Visual Factors in Instrument Displays, Wright Field Projects"---------- 13

4. Dr. Leonard C. Mead presented a paper entitled "Visual Factors in Instrument Displays, Special Devices Division, USN Program"---------- 17

5. Dr. Stanley B. Williams presented a paper entitled "Some Factors Affecting Visibility in Radar Presentations"---------- 21

6. Mr. H.R. VanSaun presented a paper entitled "Factors Influencing Ability to Identify Radar Targets"---------- 27

7. Dr. Adelbert Ford presented a paper entitled "Visual Problems in Radar Display"---------- 31

8. Dr. John Volkmann presented a paper entitled "Precision of Visual Orientation in Large Unstructured Display Fields"---------- 35

9. Dr. John G. Jenkins presented a paper entitled "Psychological Principles in the Design of Aircraft Warning Devices"---------- 37

10. Mr. M.J. Warrick presented a paper entitled "Effect of Moderate Positive Acceleration (G) on Ability to Read Aircraft-Type Instrument Dials"---------- 41

11. Dr. James Peskin discussed physiological factors in the visibility and legibility of instruments---------- 43

12. The Chairman called for questions and comments concerning the papers presented during the afternoon. An abstract of the discussion is included in the Proceedings---------- 45

Tuesday Evening

At a meeting of the Executive Committee an election of officers was held in which Captain C.W. Shilling was elected Chairman, and Major E.A. Pinson, Deputy Chairman of the Vision Committee. In accordance with the rules for operation of the Committee, their terms of office will continue until January, 1949.

Wednesday Morning, January 15, 1946

Wednesday Afternoon

VISUAL FACTORS IN INSTRUMENT DISPLAYS, WRIGHT FIELD PROJECTS

Paul M. Fitts
Aero Medical Laboratory, Wright Field

I. Role of Vision in Aircraft Equipment Design.

In few, if any, activities of modern life are the visual judgements as complex and the results of slow or inaccurate perception as serious as in flying. Return to peace-time aviation has been accompanied by what appears to be an appalling number of accidents. Predictions made last fall that this winter would see a serious impairment of air transport service have been borne out. At the same time research on new military planes is pushing on toward supersonic speeds and the threshold of human ability to perceive and react.

II. Pilot Errors in Reading Instruments.

Let me quote a few descriptions of difficulties encountered in reading and interpreting existing instruments, as given by pilots themselves. These descriptions are examples of replies to interviews in which the following question was asked: "Describe an error made by yourself or by another person with whom you were flying, involving the reading or interpreting of some aircraft instrument

"One night when I was instructing in a basic flying school, a cadet was given instructions to let down for a landing. That was the last that was heard of him that night. The next morning he called up from a point about fifteen miles from the field. What had happened was that he had started to let down and had read his altimeter as 1300 feet when actually it was 300 feet. He had crashed into a forest and been knocked out for an hour or so. Afterwards he had walked away and finally gotten to a telephone."

"A buddy of mine was flying at 1500 feet and looked up and there was a bunch of trees in front of him. The funny thing was that after it was all over and the plane had crashed, he said: 'Well, I guess I must have hit a tree'. The thing was that he had read his altimeter wrong. It was really indicating 500 feet which was just the height of the terrain at that point."

"This cadet started practicing spins at 18,000 feet. Of course spins don't break as fast at that altitude. The cadet thought the ship wasn't coming out of the spin. He had been instructed to bail out of a spinning ship if it ever got down to 3,000 feet. He looked at his altimeter and it read 13,000 feet. However, he thought it read 3,000 feet and bailed out. It took him a long time to get down to old Mother Earth. We lost one AT-6 on that deal."

"On the P-47 series airplane, there was a tachometer with a hand and also a small window showing the numbers one, two, or three. It was confusing to read because the window would register half way between two numbers and you didn't know where you were. A particular pilot that I knew had just pulled out of a dive He glanced at his instrument panel and thought he was indicating 2700 RPM. He happened to glance down again and saw he was registering 3700 RPM, which was way too high. Before he caught it, though, he had torn the inside of the prop right out."

"The airspeed indicator in our B-24 was numbered in ten miles an hour below the first hundred miles or so, and above that it was marked off in thirty miles an hour. This makes it quite difficult to read, especially when you just glance at it. While coming in for a final approach once I glanced at my airspeed indicator and misread the instrument. I was supposed to have a hundred and twenty-five miles an hour, and my airspeed got down pretty low. Luckily we caught it before anything really serious happened."

"One night when I was co-pilot on a C-47 the pilot asked me how much fuel we had. I said, half a tank on the one we were running off of. Thirty minutes later he asked me again and it still read half a tank. I first thought that something was wrong with the gauge. However, I discovered that what had happened was that I had been looking at the carburetor air temperature, which was directly below the gas gauge. The needle on the temperature gauge was pointing straight up and down, and at night I had mistaken it for the gas gauge above it. It was stupidity on my part."

"This incident happened while instructing in At-10's. I had taken a student over to an auxiliary field to give him instrument take-offs. About the third take-off (the other two had been good - everything was under control) I lined up for take-off, set the directional gyro, turned the airplane over to the student, told him he was clear to go. He started his run, and the airplane began to go off to the left just a little bit. He misread his directional gyro and gave it left rudder. He started it out easy to try to bring it back, pushing a little bit on the rudder, then a little more and more. Then he got excited and gave it full left rudder. It cut off the runway across the grass, hit the taxi strip, bounced over the fence into the air at a 45 degree angle to the normal takeoff."

"The error I make most is misreading the artificial horizon. I read it backwards. When the wing is down I think the airplane is turning the other way a lot of times. I don't make that mistake so much any more but I had a lot of trouble with it when I first started flying on instruments."

III. Survey of Current and Contemplated Research.

In the past the Aero Medical Laboratory has worked on many visual problems in equipment design. Major Pinson, who is now a member of the Vision Committee, and Doctor Chapanis, who was stationed at the Aero Medical Laboratory during the war, have reported in the past on research on such problems as the development of aviation goggles, night vision tests, night vision training, vision through transparent sections, and the relation between accident rates and the degree of vision out of cockpits of different type planes.

At present the area of research on visual problems in equipment design at the Aero Medical Laboratory is being extended to include many additional problems of instrument display. The objective of all this work is to determine the human limitations and psychological abilities of the man, so that equipment can be designed for most efficient human use. Problems now being studied or considered for future study by the Aero Medical Laboratory or Associated Universities include the following:

1. Sensory discrimination of brightness, contrast, color, pattern, and other stimulus qualities in relation to type and amount of instrument illumination and adaptation level of the eye.

2. Attention-getting value of different visual signals such as warning devices.

3. Legibility of different dial faces, styles of numerals, instrument markings, graphs, maps, and charts.

4. Interpretability of different methods of presenting information, such as various types of scales, different radar displays, techniques for representing three-dimensional space, and methods of showing the position of an airplane in respect to the correct glide path for a blind landing.

5. Optimal relationship between instruments and between instruments and controls, such as problems of instrument lay-out or direction-of-movement relationships.

In addition to these visual problems, of course, research is underway in other sensory fields, on the design of controls, and on more complex systems engineering problems.

VISUAL FACTORS IN INSTRUMENT DISPLAYS

SPECIAL DEVICES DIVISION, USN PROGRAM

Leonard C. Mead
Special Devices Center, ONR

As in any other situation involving the human individual in sensory stimulation, perception, interpretation, and response, it is often difficult or even impossible to segregate the visual factors in the instrument display problem from other features which affect this psychological chain of events. This is not to minimize the necessity for the study of those features of one's physical environment which stimulate the visual mechanism along with the experimental examination of the ensuing visual experience, but to emphasize the importance of considering this sensory phase as one aspect of a program which will lead to the specification of a set of conditions in which the individual can operate with maximum ease, speed, and efficiency. It is this latter broader program which is of fundamental concern to the speaker and his engineering colleagues. Needless to say, visual problems receive a large share of our attention.

Perhaps a few words are necessary in order to explain the speaker's connection with the Navy program. He represents the Human Engineering Section of the Special Devices Center of the Office of Naval Research. The Engineering Branch of the Center concerns itself with the development of operational equipment and synthetic training devices. These engineering developments are in the fields of navigation, armament, radar, flight and so forth, and the various sections of the Branch are so-entitled. The Human Engineering Section is also in this Branch and is available for consultation or the administration of research so as to provide psychological information for use by the engineers in these other sections. Although the importance of coordinating equipment design with the psychological capacities and limitations of the human operator does not need to be underscored to this group, the significance of such efforts has only comparatively recently been understood by the Services at large. At the Special Devices Center, however, there is practically continuous day-to-day consultation between the electronic, mechanical, and design engineers and the psychologists.

There is only one unfortunate aspect to this happy arrangement, namely, that the engineers expect the psychologists to have at their fingertips knowledge about the sensibilities of the human being which is as accurate and precise as the engineers' information concerning gear backlash or the relation between weight required for a particular structural strength. To the engineer it appears that a person trained in the biological sciences should be able to answer easily the question, "What is the best design and location for a radar scope?" The speaker ventures to assert, however, that a definite and final answer to this question cannot be found in the appropriate published literature. The biologically trained individual will preface his response by the phrase "it depends". Indeed, it does depend on a multiplicity of factors such as the size and brightness of signal, the contrast between signal and surround, the ambient illumination, the number of signals, the use to which the information will be put, the other

tasks which must be performed concurrently, and the skill and level of training of the operator, and perhaps even on the general aptitude and personality of the user of the equipment. One may then ponder the chances for success of research in such a field where there are so many interactions between the variables. The answers can be and are being found. These observations are being mentioned so as to demonstrate the nature of the conversations between the engineer and the psychologists when the former appears, asking for advice.

It is the privilege of the Human Engineering Section to be in a position to arrange the negotiations of Navy contracts calling for research in the field of psychotechnology when the engineering development under consideration provokes questions of broad and fundamental significance. Obviously this state of affairs must occur continuously, and there now exist approximately ten different projects at various colleges and universities where research in this area is now under way. As was previously noted, not all the problems are visual in nature, but it is a pleasure to note that the papers being presented at these meetings by Drs. S.B. Williams, Volkmann, Bromer, and Chapanis represent research that has sprung in one way or another from some of the development problems encountered by the Special Devices Center. Being in the embarrassing position of spending most of his time attempting to arrange for facts to be determined rather than ferreting out the answers for himself, the speaker is in a better position to present problems rather than results.

In the case of aircraft instrument design and display, the Navy problems are in many ways similar to those of the Army which have been reviewed by Dr. Fitts. One of the projects being handled by our Flight Section is designated the "functional cockpit". A mode of attack on the project has been to consider the cockpit as an empty space adequate for the normal-sized pilot and to add only those instruments and controls essential to the functional operation of the craft. A deliberate attempt has been made not to be influenced by any previously designed instrument or form of control. The job of the pilot of present-day and anticipated future models of military airplanes is being analyzed in terms of those activities which the pilot and his machine should be expected to accomplish. Problems of instrument design and display are then considered in relation to the optimum and most direct way of presenting this essential information. The thinking in this way has shown that many conventional instruments may not be needed. It has also led to proposals for types of instruments which have not yet even been given engineering consideration.

One result of this type of approach has been the conclusion that many instruments are designed to give quantitative information regarding one aspect of engine performance or plane attitude when such detailed knowledge is not required. An instrument which requires the eye to pick out one of several pointers, of differing size, length, or color, and to relate the selected pointer to one of several scales having various markings and numerals can sometimes be replaced by a single signal which merely indicates whether a particular condition is present or not. In other words, the pilot does not always need to know "how much" of a particular phenomenon is occurring but merely to know whether or not it is occurring to a safe or dangerous degree. The substitution of indicator lights or colored markings along a scale to show particular conditions are illustrations of this principle. The Flight Section has recently applied the principle in the development of

a single box which gives this "all-or-nothing" data for six engine instruments. A single light represents each of the engine indications such as temperature, manifold pressure, etc. For each flight condition (take-off, level flight, glide, etc.), if conditions are safe, the six lights make up a horizontal row. If one item is unsafe, however, the light appears higher or lower than the rest of the row and practically forces its own detection. By such an arrangement, visual comprehension time is much reduced, and the pilot is enabled to use his visual processes in other ways. The application of this general technique is another illustration of the trend to simplify the sensory and cognitive features of instrument display by assigning to the instruments themselves the computational or assessment features of the event concerning which information is desired. Obviously, this complicates the engineering problems but simplifies the human problems in the man-machine combination.

In the field of radar and communication instruments, the Navy has taken the Combat Information Center as a point of departure for research on the place of the human individual in military information systems. At some stage in a system of this nature visual and/or auditory factors will cut across the speed or accuracy of solution of the events dealt with by the equipment. The Systems Research Project, which is attacking this whole problem, is conducting a number of experiments on those visual factors which relate to the detectibility and legibility of radar signals. Personnel engaged on the Project will present some of their results to this group later on the program. Other members of the staff will describe further aspects of the work in the field of scale and dial design and location thereof.

A final consideration concerning research in this general area should be presented. All too often the question of visual factors in instrument displays is raised with respect to a specific engineering design problem for a particular military situation. The solution of these immediate day-by-day issues is, of course, important. But it is hoped that the research investigators who concern themselves with these matters will endeavor to discover and enumerate findings which will have general application to instrument problems at large. If this broad attitude can be taken by those who are working, for example, on the optimum design of navigation instruments for aircraft, it may be that their findings can be generalized to cover similar questions for other types of installations where instruments of related design could or should be incroporated.

SOME FACTORS AFFECTING VISIBILITY IN RADAR PRESENTATIONS

Stanley B. Williams

Johns Hopkins University (Navy)

Primary Variables

At present, our research is directed to those factors which affect the visibility of a single target on a Plan Position Indicator. For a complete study of the conditions of visibility, we would need to control separately the following variables: (a) Target brightness; (b) Target size; (c) Definition of targets, i.e., rate of change of contrast; (d) Background brightness; (e) Background composition (clutter); (f) Duration of targets.

In radar set-ups none of these is normally under direct control. Instead, each is dependent jointly on a large number of secondary variables, which derive from the nature of the circuit or of the conditions of operation. The manner in which they interrelate in the production of the primary or visual variables is one of the goals of our research. Our present equipment is suited for studying only some of these inter-variable relations; equipment now in construction will, it is hoped, permit study of nearly all of them. Up till now our experiments have related visibility to secondary rather than primary variables. Nevertheless, some data of value can be obtained. As examples, two sets of studies will be presented: one dealing with visibility and intensity; the other, with visibility and target size.

VISIBILITY AND INTENSITY: Effect of CRT Bias

Although there are many factors which affect the brightness of a PPI scope, the bias placed on the control grid of the cathode ray tube is the main intensity control. Since it is negative, the less the bias, the greater is the number of electrons bombarding the phosphor on the face of the scope and, therefore, the brighter is the scope, at least below a certain limit at which the phosphor becomes saturated. The relation is not linear, but over a wide range it may approximate linearity. Brightness measurements, by a somewhat inexact method, have been made of the sweep line, i.e., the integration of successive pulse echoes, on a standard PPI scope with a P7 phosphor. Measurements to date indicate a range of approximately 100 to 1×10^{-4} millilamberts from maximal excitation to the lower limit likely to be used in radar operation for this particular scope. This range represents a range in bias voltage of approximately 12 volts. Over perhaps half of this range, i.e., for a dim scope, the assumption of linearity for the brightness-voltage function would not be appreciably in error for practical purposes. This is the half-range corresponding to normal operation. Within this range, a change of one log unit in brightness is accomplished by a change of about one volt of grid bias. For visibility, then, grid bias is of critical importance.

When grid bias is high, the scope is dark and a target echo is seen as a light pip on a dark ground: the minimum visible pip is comparable to an absolute threshold. When bias is lowered, the minimal pip is seen against a brighter background and the visibility scope is comparable to a differential threshold for brightness. Decreasing bias, of course, increases proportionately the brightness of every voltage admitted through the video channel, including noise and fixed echoes such as sea return. It does not affect the signal-to-noise ratio.

One would expect the greatest physical contrast between target and background on highly biased scopes, so long as the bias level were still within the linear portion of the brightness-voltage curve. One would also expect a decrease in contrast as the bias is lessened to the point where phosphor saturation effects occur. One would, therefore, expect that optimal visibility on a scope would occur at the lowest bias (highest brightness) possible without phosphor saturation.

Results Experiments have confirmed the prediction. In every type of cathode ray tube yet studied there has been found a biasing voltage which is optimal for visibility. This voltage is low and probably is just short of phosphor saturation. Some results for a 7BP7 tube are shown in Figure 1. The abscissa values are volts relative to a visually determined reference voltage. The ordinate is an arbitrary visibility scale, units being decibels of attenuation of a reference voltage. With attenuation units, the higher the score, the lower is the threshold. It is clear that steadily decreasing the bias gives continuously better visibility up to a maximum, after which further lowering of the bias actually impairs visibility. The data of this graph were taken with a noiseless, relatively homogeneous background.

The data of Figure 2 were taken with varying amounts of video noise, from none to 1.53 volts rms, which introduces clutter into the background. In spite of noise, the function remains remarkably similar. The maximum is still evident in each of the noise curves. It should be explained that the noise we are using has two effects: (1) it adds brightness to the screen; and (2) it tends to introduce an element of form discrimination into the visual task. Both of these effects contribute to the loss in visibility produced by noise on an already bright scope.

It is interesting to note that at certain higher bias levels it is possible for noise to be an advantage rather than a disadvantage. In Figure 2, the visibility scores for the 20 volt bias are best when a medium amount of noise is on the scope. This no doubt is due to the brightness added by the noise. Further, it is to be noted that noise becomes less critical as a determiner of visibility as the bias is increased.

Because of difficulty in accurately measuring the bias voltage, we have no great confidence in the absolute abscissa values in Figures 1 and 2. They are meaningful only on a relative scale. We now use a visually determined reference point as the anchor of the scale, namely, that bias voltage which allows the sweep line to be just visible in foveal view. As checked by an electronic photometer, this reference point, visually determined, appears to be a very reliable value. It is the zero in Figure 1 and represents a bias not far from that which is commonly employed by radar operators.

Conclusions The bias voltages which give the best visibility are not the higher ones. Although high bias makes for greater contrast, it does not make for greater visibility. The explanation must lie in the eye, and not in the scope. Physical measurements indicate that the optimal bias for the 7BP7 tube represents a scope brightness of approximately one millilambert. Reference to the Tiffany data reveals that this is a brightness level just short of that at which contrast sensitivity of the eye is maximal, for targets of this size. In other words, sensitivity of the eye cannot be the limiting factor. Higher bias voltages than the optimum represent brightnesses at least two or three log units below this, i.e., a range of low contrast sensitivity for the eye. Lower voltages than the optimum are less favorable for target detection, not because they represent brightness too great for the eye, but because they represent the limits of excitation of the phosphor in the scope. Therefore, it appears likely that the lefthand part of the curves in Figures 1 and 2, namely, the increase in visibility with decreasing bias, is a function of the sensitivity of the observer's eye, whereas the right-hand part of the curves is a function of the sensitivity of the phosphor in the scope.

VISIBILITY AND TARGET SIZE

With present equipment, the length and width of a target cannot be varied independently of other factors affecting visibility, but some aspects of target size can nevertheless be studied indirectly in four different ways:

1. Varying distance of eye from scope. This changes both dimensions of the target.

2. Varying the range scale of the remote indicator. This changes the width without affecting the target's length. It also changes the scope brightness, for which a compensation may be made.

3. Varying the angular beam width of the radar. This changes the length of the target, i.e., its greater dimension, without affecting width.

4. Varying the range position on the scope. This changes the length but not the width of the target. However, as length increases by this method, target brightness decreases because the increased length is accomplished by spreading a unit energy over greater area.

Each of these methods of changing target size has been studied, using a stationary target on a PPI scope coated with a P7 phosphor. Antenna rotation rate was constant at 10 rpm; pulse length was 3 microseconds; and pulse repetition frequency, 600 per second. A method of adjustment was used in determining thresholds.

The results are as follows:

Method 1. Effect of distance from scope.

Observations were made binocularly with the eyes at 6 inches and again at 24 inches viewing distance. The target was 20 degrees in angular length on the scope. A comparison of the 6 and 24 inch viewing distances was made under each of eight combinations of three conditions: (noise and no noise (video); low and high tube bias, i.e., high and low scope brightness; illuminated and non-illuminated scopes (external illumination of about 8 foot candles). At 6 inches the target subtended an area about 43' by 5°; at 24 inches its area was about 11' by 2°15'.

Results (Table 1) indicate greater visibility of the 6 inch distance in 7 out of the 8 comparisons. The largest difference was 8.3 decibels of signal power, obtained with a dark scope, no video noise and no external illumination, -- very nearly the condition for determining the absolute brightness threshold. Probably all but the two smallest differences are significant; variability is such as to place confidence only in differences of 2 db or greater.

Table 1

Advantage of 6 inch over 24 inch viewing distance under three conditions

	Non-illuminated scope		illuminated Scope (8f.c.)	
	Dim Scope	Bright Scope	Dim Scope	Bright Scope
No Noise	8.3	5.3	2.3	3.3
Noise	3.3	-1.3	0.8	2.3

These data indicate that when the discrimination task is one of discriminating brightness differences only, the factor of size is important, but can become negligible relative to other factors such as noise or external illumination.

Method 2. Effect of range scale

Using a target of 20 degrees angular length on the scope and a bright scope background, with other conditions constant as before, visibility was determined under five conditions of magnification of the width dimension made possible by the five range scales available on a remote indicator; the 4, 10, 20, 80 and 200 mile scales. With a 3 microsecond pulse, the angle subtended by the target's width dimension at 12 inches distance varies from 2°11' for the 4 mile scale to 2.2' for the 200 mile scale. The target's length measured 14° on the scope, which amounts to about 2° at the 12 inch viewing distance. Presented in Table 2 are visibility scores for both noise and no noise conditions with a fairly low scope brightness (approx. 1×10^{-3} m.l.)

Table 2

Visibility on Different Range Scales. Scores are db of Attenuation of a Reference Signal Voltage

Range Scale (Miles)	4	10	20	80	200
Width of Target	2°11'	56.5'	21.5'	5.0'	2.2'
No Noise	31.0	27.6	27.0	24.5	21.6
Noise	30.0	26.3	25.0	24.5	22.0

There is an average loss, for all conditions, of about 9 db of signal power in going from the 4 to the 200 mile range scale. This loss must be largely attributed to the narrowing of the target width, because the several conditions were approximately equated for brightness by a visual method. If brightness is not equated, the loss in brightness eliminates the advantage obtained by the increase in width and visibility is approximately the same on all range scales.

Method 3. Effect of Target Length

Several experiments on the effect of length of the target on its visibility have indicated an increase in visibility with greater length. We have not tested the limits of this effect because as yet we have not been able to secure targets shorter than 12° on the scope. However, from 12 to 60 degrees, there is continued improvement in visibility amounting to about 10 db of signal power.

Method 4. Effect of Range

As a target is increased in range it moves from the center of a PPI toward the periphery, gradually becoming larger in angular length. However, the increase in length is accompanied by no change in total signal energy. The same energy is simply spread over a larger area. There is, therefore, a corresponding loss in brightness. All experiments thus far have indicated no effect of range on visibility, other things constant. As an example, one set of data is presented in Figure 3. The ordinate is a visibility scale, and the abscissa the distance from the center of a 7BP7 scope which has about 3 inches usable radius.

When noise is present, thresholds are more variable. We conclude that the constancy of visibility at different ranges is brought about by an exact compensation of brightness decrement by area increment.

Conclusions With present experimental equipment we cannot separate, one by one, each of the primary size variables from the complex of other variables. In varying width of target, we also vary other aspects of the circuit which in turn affect brightness, form, or some other dimension. Nevertheless, the combined results of several studies permit certain conclusions:

(1) The area of a target pip appearing on seven-inch scopes at normal operating brightnesses is of such order of magnitude that both its length and width are variables significantly affecting visibility. The larger the pip, the greater its visibility.

(2) The cathode ray tube is a display device which normally compensates many area changes by brightness changes. Therefore, the effect of size is not always immediately apparent.

(3) The limits within which increases in target brightness can compensate for small area, or conversely, increases in area can compensate for less brightness (as with weak signals), can be determined for any given type of radar scope. An exact determination will require somewhat better control of circuit variables; that is, better experimental equipment than we now have. This equipment is now being assembled and will be ready for use in the near future.

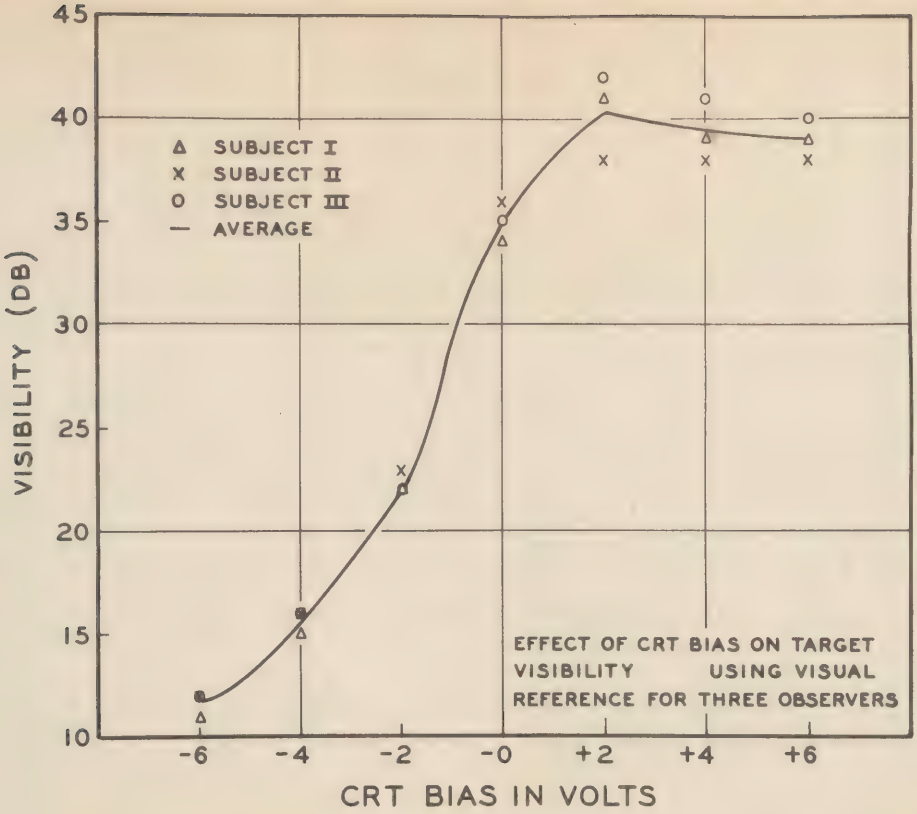

Figure 1

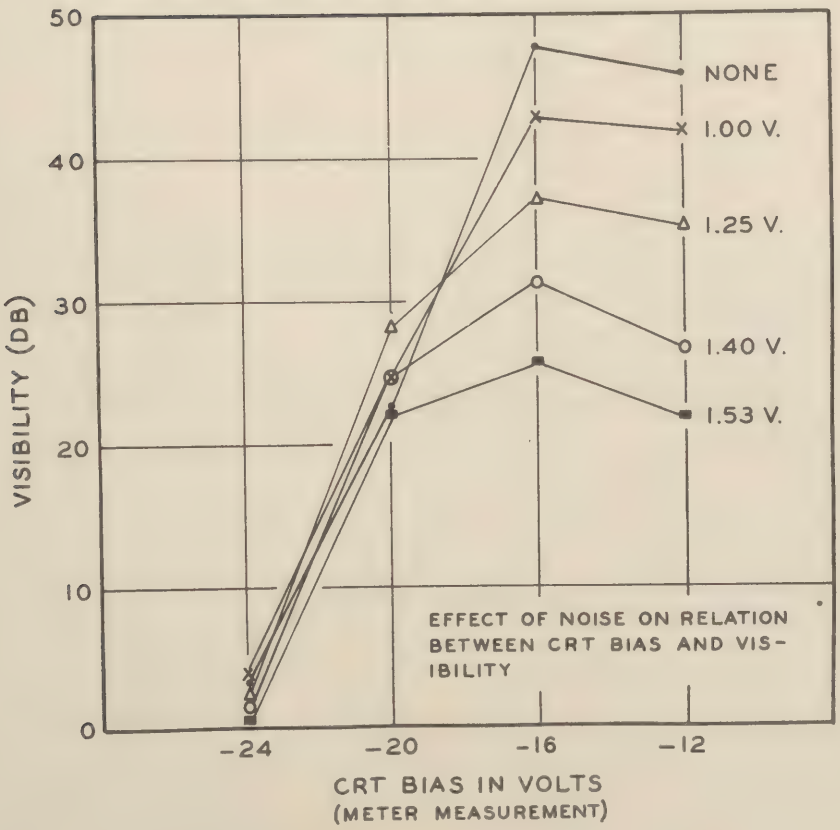

Figure 2

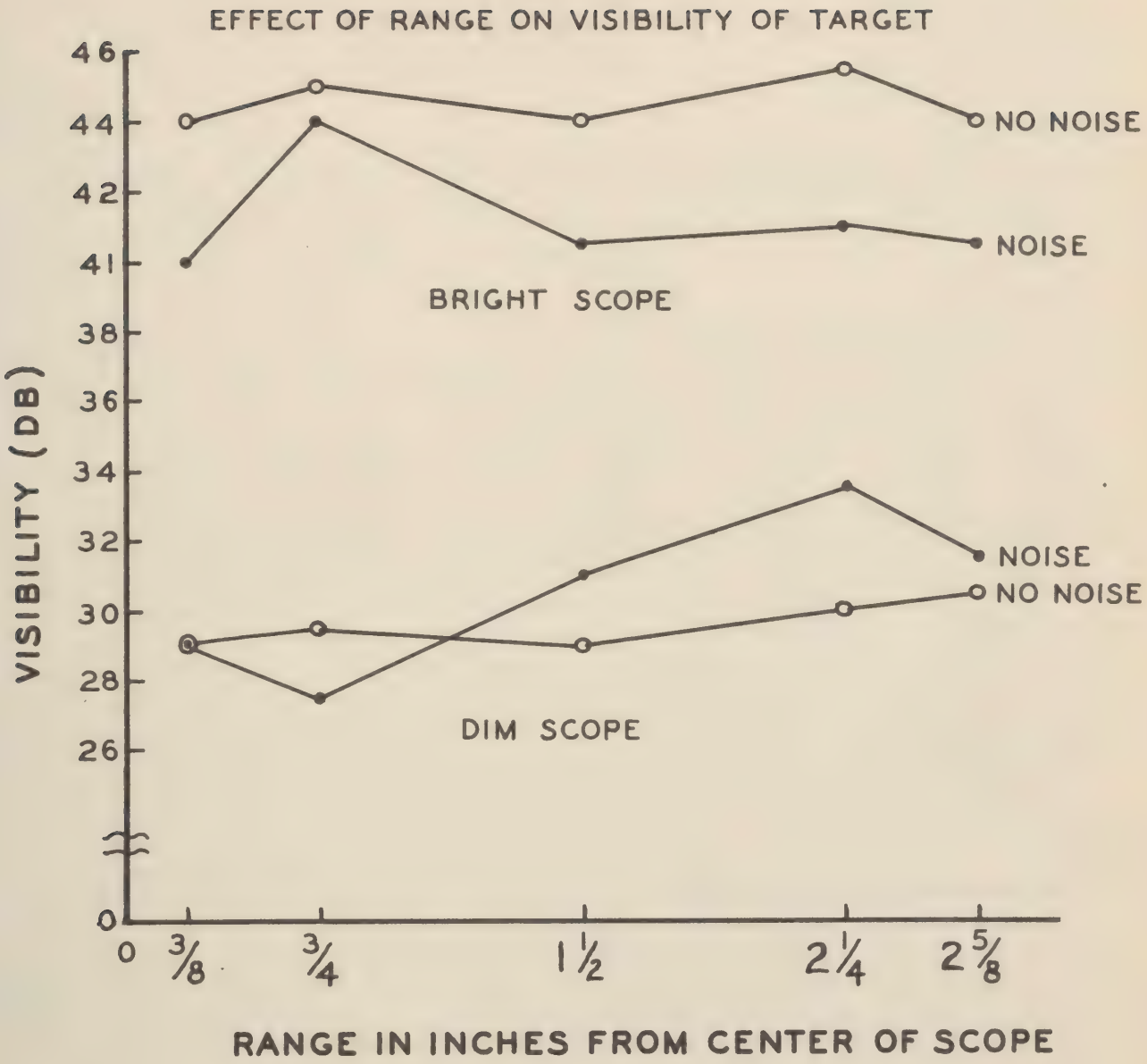
EFFECT OF RANGE ON VISIBILITY OF TARGET
VISIBILITY (DB)
46
44
42
41
38
36
34
32
30
28
26
0
NO NOISE
NOISE
BRIGHT SCOPE
NOISE
NO NOISE
DIM SCOPE
0
3/8
3/4
1 1/2
2 1/4
2 5/8
RANGE IN INCHES FROM CENTER OF SCOPE

Figure 3

FACTORS INFLUENCING ABILITY TO IDENTIFY RADAR TARGETS

H.R. VanSaun
Aero Medical Laboratory, Wright Field

Introduction.

The study which I am going to present today concerns the comparative speed and accuracy with which targets first presented on a radar navigation scope can be identified on two types of radar bombing scopes. It has been published as Memorandum Report No. TSEAA-694-5.

The factors influencing an airborne radar operator's ability to identify radar targets may be grouped under two headings. First, the observer must be able to recognize the various patterns of light and shadow on his scope for what they are. The various terrain features are represented on the scope as characteristic returns. Water gives practically no return; islands on water appear as bright returns against the dark background. Built-up areas on land, such as towns, appear as bright areas against a less light background. Rivers, lakes, and inlets appear as dark areas with bright lines representing the far shores. Mountain ranges appear as bright areas with shadows behind them. Bridges appear as sharp bright lines against the dark water. Factory and business areas ordinarily give brighter returns than residential areas and less built-up areas. Because these terrain features differ considerably, the task of deciding whether a return represents a river, lake, town, or mountain, is usually not difficult. Occasionally there is some problem as, for example, deciding whether a return is a bright cloud or a town. Specifically identifying a return once it has been recognized as a town, however, is a much more difficult task and introduces the second group of factors affecting target identification. By noting the size, shape, and brightness of the return, the radar-navigator is sometimes able to identify or name it by comparing it with his chart. Frequently, however, returns from towns do not have characteristic shapes or sizes for all angles and altitutes of approach, and identification is possible only by the pattern which the radar echos form in terms of the distances and bearings between them - patterns which are recognizable on the navigator's chart. Similarly, the bombardier's identification of aiming points within towns or target areas, crucial to accurate bombing, is largely dependent upon the position of the aiming point relative to other elements in the target area.

Certain similarities in the job of the radar-navigator and bombardier have just been mentioned. Other aspects of the task of navigating and bombing by radar differ considerably. As a navigational instrument, it has been assumed that the radar scope should present a display of as great an area of the terrain around the aircraft as possible. The inclusion of azimuth or north stabilization in the equipment causing the scope display to be oriented with north at the top has also been regarded as a desirable characteristic for navigational use, inasmuch as such an arrangement enables the navigator to transpose the radar display directly to his north oriented maps. For bombing, however, only the target area is of interest to the bombardier. This area, it is presumed, should be presented as large and with as much definition as the equipment is capable of producing. Moreover, it seems desirable for bombing that the radar display be oriented to the heading of the aircraft rather than to north as is the case for navigation.

Radar installations for the two jobs, navigation and bombing, have generally been designed in accordance with these assumptions.

The advent of new high speed bombardment aircraft where design characteristics seriously limit the space available for personnel and, thus, require the consolidation of the duties of navigator, radar operator and bombardier into one job to be performed by one man, has raised certain problems regarding the design of the equipment to be so used. Two such problems are - first, what type of radar bombing presentation makes for the most rapid and accurate identification of targets first presented on the PPI navigation scope, and second, what is the effect on the speed and accuracy of identifying targets when the PPI scope is north stabilized and the bombing scope is heading stabilized. It is with these two problems that the present study is concerned.

Bombing Scope Interpretability Study.

In attacking the problems of the optimal bombing scope to be used in conjunction with the PPI scope, prototypes of the two basic display systems, cartesian grid and polar grid, were compared on the basis of the speed and accuracy with which targets presented on the PPI scope were recognized on the bombing scope. In attacking the problem of the effect on efficiency of shifting the attention from a north stabilized PPI scope to a heading stabilized bombing scope, a comparison was made of the speed and accuracy with which targets were recognized when the scopes had the same orientation, and when the navigation scope was north stabilized and the bombing scope was heading stabilized.

A test was devised utilizing 200 pairs of especially constructed simulated radar scope photographs. One member of each pair consisted of a PPI navigation scope photograph with a terrain feature indicated as a target. The other member of the pair was a bombing scope photograph with the same target and a number of misleads indicated by letters.

The test was organized into four parts and administered to four groups of 12 subjects each to obtain comparative data on the two bombing scopes under conditions of (1) both scopes being heading stabilized, and (2) PPI scope being north stabilized and the bombing scope being heading stabilized.

Each part of the test contained 50 items. Part 1 consisted of heading stabilized PPI scope photographs followed by heading stabilized polar grid bombing scope photographs. Part 2 consisted of PPI scope photographs identical to those in Part 1 followed by heading stabilized cartesian grid bombing scope photographs. Part 3 consisted of north stabilized PPI scope photographs followed by heading stabilized polar grid bombing scope photographs and Part 4 consisted of PPI scope photographs identical to those used in Part 3 followed by heading stabilized cartesian grid bombing scope photographs. Each of the 48 subjects took all four parts of the test. For each item they were required to study the target indicated on the PPI photograph and then turn to the bombing scope photograph, locate the terrain feature they believed was the target, and mark their answers accordingly. They were not allowed to turn back to the PPI photograph. Strict, identical time limits were imposed for each part of the test.

The results of the administration of this material were analyzed in terms of the number of targets correctly recognized on the bombing scopes and in terms of the number of errors in target recognition within the time limits of each part of the test, The result of this analysis definitely indicated that in terms of the number of targets correctly recognized, the polar grid bombing scope is superior to the cartesian grid bombing scope, both when the PPI scope and the bombing scope have the same orientation and when the scopes are differently oriented. One of the critical ratios between the means for this factor is significant at the 1 percent level, and the other is significant at better then the 5 percent level.

The data concerning the number of errors in target recognition are not as clear cut only the critical ratio between the mean number of errors when the bombing scope and navigation scope have the same orientation is significant.

However, the other critical ratio for error scores on this variable is in the same direction. Taken as a whole these facts tend to support the superior interpretability of the polar grid bombing scope. It is believed that the superior performance exhibited with the polar grid display is due to the fact, that it expands the image of the terrain proportionately in all directions, thus, retaining the original configuration, whereas, the seemingly advantageous horizontal expansion of the cartesian grid display results in a distorted image that sufficiently masks the original configuration of terrain features so as to make them difficult to recognize.

The data concerning the effect of PPI scope orientation on bombing scope interpretability presents a similar picture to that just discussed. In terms of targets correctly recognized, the situation wherein both PPI and bombing scopes have like orientation is superior to the situation when the scopes are differently oriented. More targets were correctly recognized in the former situation on both types of bombing scopes, the critical ratios all being significant at the 1 percent level. The error scores are again less informative. Only the critical ratio between the number of errors on the polar grid scope shows a significant difference between the two conditions. Taken as a whole, the data indicate superior performance with displays having identical orientation. This is to be expected inasmuch as the change in orientation of bombing scope, manifest when it is heading stabilized and the navigation scope is north stabilized, adds but another confusing factor to the altered figure-ground relationship inherent in the problem of shifting the attention from one scope to the other.

Conclusions.

The results of this study, then, may be taken as "partial" evidence that when an operator is to serve both as navigator and bombardier, it is more efficient to present radar bombing information on a polar grid bombing scope than a cartesian grid bombing scope, and that the operator will be more effective in interpreting the bombing scope when it and the previously presented navigation display have the same orientation. I say "partial" evidence because some other variables, such as the effect of simultaneous presentation of the two scopes, should be investigated to complete the picture. Investigation of these variables is planned for future research.

Page 30 missing

VISUAL PROBLEMS IN RADAR DISPLAY

Adelbert Ford, Lehigh University (Army)

Because of limitations of time, I shall presume that you are all familiar with the appearance of standard radar scopes, including B-scan, PPI, and sector-scanning types.

The Lehigh contractors with the Army have undertaken those special problems which have to do with complex radar installations used for the ground control of planes making blind landings in fog and other conditions of low visibility, heretofore designated as GCA. The operating model now in use requires two PPI scopes, at long and short ranges, two sector scopes for azimuth at 10 and 2 miles range, and two sector scopes for indicating elevation at 10 and 2 miles range. This system requires five operators reporting information and a control man who "talks the pilot in" by a two-way radio voice channel to the plane being landed.

New equipment is already in the preliminary-model stage. It has been proposed to reduce this five-man team to only one man who must execute all the functions originally performed by the five men, if possible. This is in the interests of economy of personnel, reduction in space and weight of the radar installation, greater portability for Army use, and a reduction in coordination problems among the various operators of a complex system. Obviously the new systems seem to involve possibilities of psychological hazards when one man is required to digest the significance of several forms of presentation. This is not quite as bad as it appears, at first glance, since the engineers have already succeeded in bringing the various presentations into a more compact area of visual observation. The new equipment will probably require the following factors in the performance of a radar operator:

New Operating Requirements

1. Spatial judgments reported directly from scope observations. (Formerly an operator merely tracked a "blip" with a hair-line cursor, and deviations were read from a special meter by another operator.)

2. Detecting signals promptly in the presence of "ground clutter" and "grass." Also, keeping contact. This is an old problem, but an urgent one.

3. Detecting the direction of movement of a signal promptly and anticipatin the next probable positions.

4. Making accurate judgments of space and direction from "blips" of variable shape, intensity, and size. (Some of the blips are round, some oval, some shaped like a dumbell, some bright, some dim, etc.)

5. Judging the movement relations of two or more targets going in different directions at various altitudes, various azimuth positions, and various ranges.

6. Reading and reporting from a number of scopes in rapid succession by a single operator, as PPI, azimuth, and elevation.

7. Reading spatial values from superimposed scope scales.

8. Keeping visual orientation when coordinates are rotated, probably 90° from normal position.

9. Detecting improper focusing of CR beams, to improve scope resolution as needed.

10. Adjusting gain controls to keep maximum discrimination between target signals and other signals are needed.

Psychological Problems

1. We shall be required to measure and know the relative accuracy with which any well-trained operator can report spatial deviations of a signal from a superimposed "glide-line" on a sector scope. We already have reason to believe that these reports will be influenced by tendencies toward optical illusions due to perspective habits, oblique lines (Poggendorf illusion), and warps of judgment involved in the classical laws of filled and unfilled spaces. This may require an improved scope design.

2. These measurements must be made with representative interference conditions. The typical job simulator, with artificial screen and target signals, usually gives uniform "blips" and clear patterns of movement with all of the real psychological hazards omitted. This only leads to a sterile presentation in which the most important psychological problems of presentation have been disregarded.

3. We should study the conditions which lead to the visual perception of movement on a radar screen. We need to know the influence of various degrees of screen persistence (phosphorescence) experimentally. We need to know the angular error from measured data.

4. We must be able to measure the effect of signal variability, as it occurs under real conditions. Again, we cannot use a job simulator which presents artificial signals and interference effects. Until the engineer can give us a radar set which presents a row of uniform blips, we must use the kind of signals, round, oval, dumbell shaped, bright, or dim, which an operator will have to use, or we shall not have accurate measurements of visual discrimination.

5. Since one operator will have to keep his visual orientation for several targets, we must measure the accuracy and reliability with which a well-trained man can execute such a multiple task, and we must try to determine what conditions will make for the complete exclusion of errors. In directing the blind landing of a plane the operator simply cannot afford to make even one mistake.

6. Since the proposed operator will be required to read and interpret two or more presentations in rapid succession or alternation, we must measure the effect on accuracy of reporting when attention to one interferes with attention to the other. This is a psychological complication experiment, with human lives as the stake.

7. Since this operator must now report spatial distances directly from the "glide-line" of a plane landing, superimposed on the scope, we must experiment with various types of scope scales which will certainly make the job simple and free from optical illusions.

8. Since an operator will be required to visualize the pilot's position, no matter what the position of the coordinates on the scope, in order to direct the pilot in a blind landing, we must find out who can and who cannot do this. In other words, how accurately can this radar operator, entirely from his scope signals, imagine himself sitting by the side of the pilot and talking as if he were facing the landing strip? We must have tests of such capacity to reorganize visual space orientation, and it will be better if these tests are in the form of real scope situations.

9. Some of the problems deal with the more simple factors in visual acuity. The operator must keep his scope focussed and adjusted for best discrimination. Again, the best test will be the one which uses real scope patterns.

10. It has been observed that when scope signals, of variable physical intensity, are raised to a brilliance which is too high, they all look as if they were of the same intensity. This is merely an extension of an old pscho-physical law with reference to the upper limen of discriminability. But we shall be required to test an operator's ability to avoid this cause of loss of signal differentiation. Note paper of Dr. Williams for biasing results of scopes.

The Experimental Goals

I have already indicated that some of these problems simply cannot be studied by means of a simulator with artificial blips and scope patterns. We must have the closest possible approximation of the real thing. Yet it is also necessary to be able to present standard problems, over and over, to the same subject or different subjects.

It is for this reason that the Lehigh group is attempting a new simulator which is expected to work on the basis of a photographic record of real radar-controlled blind landings. Such a simulator has been attempted before, but we hope to achieve the avoidance of past errors. This one we believe, will have the following points which are necessary for complete realism:

1. Experimentally varied scope persistence (phosphorescence).

2. A sharply visible sweep line, as in a real scope.

3. The blips and ground clutter from an original real situation.

4. A scan-rate exactly matched to the original record.

5. Control of plane deflection from a superimposed glide-line.

6. Experimentally varied scales for measuring spatial judgments.

7. Control of signal intensity, for the whole field, but not for any single part.

8. Control of focussing resolution on the screen.

No simulator is free from imperfect rendition of real situations. This is merely an attempt to get closer. It is the only way in which we can work in such a manner that we can hope to present close approximations of the stimulus situations required for answering the foregoing visual problems. The construction of the device is now about 90% finished, and the photography of field runs has already begun, with four ten-mile azimuth records from Andrews Field collected last week.

ABSTRACT

PRECISION OF VISUAL ORIENTATION IN LARGE UNSTRUCTURED DISPLAY FIELDS

John Volkmann
Mount Holyoke College (Navy)

Some military situations call for the rapid estimation of such quantities as the bearing of a target and its range, course, and velocity just as soon as a few successive positions of the target have been plotted on a large display field. Speed is more important than accuracy; there may be no time for the making of precise measurements with human assistance or mechanical aids. What can the personnel observing the display do rapidly and without assistance? There is need for basic information on the discrimination of visual angular orientation, visual extent, and similar variables. The present experiments have dealt with the discrimination of target bearing, or angular orientation about the center of a circular display.

Obviously the estimate of target bearing in any practical situation will be aided by a set of bearing markers on the face of the display. But because the human subject comes to the experiment equipped with his own visual frame of reference, consisting at the least of the subjective horizontal and the subjective vertical, and because it was desirable to determine the effect of adding bearing markers one by one, the study began with no markers at all - an "unstructured" stimulus-situation.

In the first experiment, 33 female subjects sat within a wedge-shaped seating area in the rear of a dimly-lighted auditorium, and viewed a 4-foot circular display-screen suspended vertically in front of them. The plain black frame of the screen stood out against a large white curtain, which covered almost the entire end of the auditorium. The display screen was suspended by fine, non-visible wires; there were no distinguishing features in or about the screen which would serve to mark off one presented bearing from another. Once every 6 seconds a line of light 56 cm. long and 4 mm. wide appeared on the screen for 0.5 seconds. One end of the line was located at the center of the screen, and extended almost to the frame of the screen. The subjects were instructed to estimate the apparent vertical as 0 degrees, the apparent horizontal as 90 degrees, and other angular orientations in accordance with these; to designate lines inclined to the left of the vertical as negative and those inclined to the right as positive. The actual presented bearings ranged from -10 degrees to plus 100 degrees; there were 35 values of bearing in all.

When the means of all the estimates of all the subjects are plotted against the presented bearing, a surprising accuracy of estimate appears. The mean errors at most presented bearings are less than 2 degrees; the maximum error between 0 degrees and 90 degrees presented bearing is 4.97 degrees. The individual estimates of individual subjects vary widely, however, at most presented bearings, and the well-known round-number tendency appears. At zero degrees and 90 degrees (vertical and horizontal respectively) this variability is greatly reduced. There is some reduction in variability, though much less, in a broad range of presented bearings centering about 45 degrees. Analysis of the mean errors in estimated bearing shows highest accuracy at or near 0 degrees, 90 degrees, and 45 degrees.

A subsequent experiment employed shorter lines, one being 14 cm. long and one only 4 cm. long. Only a small increase in the variability of estimate resulted even from the extreme shortening of the bearing-line.

With the data on the 14-cm. line as a basis for comparison, a single long line was added as a bearing marker at 30 degrees. This line was continuously projected on the screen, and the 14-cm. stimulus-line appeared briefly within it or displaced from it, depending on the value of presented bearing. The effect of the bearing marker was to reduce mean error and variability almost to zero at 30 degrees, and to reduce the variability substantially in a broad surrounding region. Unless the estimates of individual subjects, when analyzed, indicate the contrary, it would seem possible to space bearing markers as far apart as 15 degrees, and still to retain a reasonable degree of accuracy.

AIRCRAFT WARNING DEVICES

John G. Jenkins
University of Maryland (Army)

This is a progress report on the Battle of Space, rather than a progress report on a research project as such. By the term "Battle for Space" I have, of course, no reference to any international search for Lebensraum. I mean only to imply that Maryland, like so many other universities today, has plenty of almost anything but space - and that he who would do research must first find a place to set up his equipment and run his subjects. And this, at a time when classes run until late Saturday afternoon and a converted greenhouse may serve as a classroom, is no simple problem.

We thought we had the problem licked. In making our proposal to the AAF for research on aircraft warning devices, we asked for an air-conditioned Quonset Hut. When it was announced that such a hut would be delivered, we thought our troubles were over.

As a matter of fact, they were just beginning. In the first place, the university landscape specialist folded his beard over his eyes and wept, when asked where we could put up a hut among his carefully landscaped buildings. He recovered, however, and picked out a site down behind a knoll and out of the landscaping pattern. Since we expected to be using up to 125 db of synthetic airplane noise, that was all right with us, for we suspected that we should not necessarily grow in popularity if our noise-generator were placed too close to classroom buildings.

The hut itself ultimately arrived. This meant that we had to add the erection of one hut, Pacific style, to the woes of a Superintendent of Buildings and Grounds who was already engaged in directing the construction of some sixteen buildings, varying in nature from girls' dormitories to a high-speed wind tunnel. The gentleman in question is a veteran who is alleged to have been responsible for clearing the beaches of Normandy after the invasion. He reports, in confidence, that this task was, comparatively speaking, an idyllic vacation, as compared to his present job of housing GIs by the thousand, building new classroom buildings without either bricks or straw, and erecting Quonset huts for insistent psychologists.

With his indulgence, however, we finally got the footings poured and the hut erected. We even remembered to move the Link Trainer onto the floor before the top of the hut was put into place, thereby eliminating the necessity of taking the hut apart after it had been completed.

Since we had meanwhile been busily constructing our basic apparatus, we were now ready to go. At this point, the calendar intervened. As we might possibly have predicted, November was followed by December. The ambient temperatures dropped to mean levels normally found in suburban Washington in December. Before we could make any regular research runs, it now became

necessary that our air-conditioning gear - most insightfully requested in our original research proposal - should be connected and set into operation. This, it appeared would require the attention of a new set of specialists. The specialists, we learned were, at that time, either (a) ill or (b) working many hours a day at other and more important tasks.

The dawn of the New Year, I am happy to report, has brought a millenial change in the tactical situation. Artisans have appeared - out of the nowhere - and have installed the air-conditioning equipment. They assured me, as of my day of departure for this trip, that only a small metallic object, known as a reducing gear, stood between us and functional adequacy of the hut. Assuming that this gear is procurable within finite and measureable time, we shall at long last be ready to begin our first research runs.

Except for a few tentative runs - and those with atypical subjects - to give us some general idea as to the extent to which learning may be a factor to be reckoned with in our test-scores, I can report only on our intentions. In order, however, to take advantage of the opportunity to hear your suggestions and criticisms, I shall be glad to report our general research design today. It is the design under which we expect to be able to go to work on the first day of the Spring Semester, all other conditions permitting.

You are all aware, from the title of the project, of the stagesetting for our research. Even with light training planes, the calls on the attention of the pilot are so heavy that it has been found necessary to supplement his visual indicators with other means of informing him that some necessary adjustment has not been made. Intermediate trainers, as you well know, are equipped with horns which automatically begin to blow if the pilot allows air-speed to drop below a specified level without lowering his landing gear. This warning signal has prevented many a belly-landing and has doubtless saved some millions of dollars of aircraft from being entered on the retired list. You are also aware that it fails in its purpose occasionally, as attested by the pilot who makes a perfect belly landing and then comments - as he walks away from the wreckage - that he heard the horn but was too busy with a cross-wind landing to feel anything but annoyance over this auditory invasion of his privacy.

Move from the 100-120 mile-an-hour trainer to the P-80, and from the P-80 to the truly supersonic types of aircraft, and you transform the automatic warning signal from a friendly helper into a vital necessity. The pilot of such aircraft simply will not have time enough to read many dials, no matter how elementary or how well-arranged those dials may be. Some considerable part of the necessary information about the functioning of his airplane must be supplied to him by automatic signals, probably most frequently of the all-or-none type. It is the purpose of our researches to try to determine which types - and which combinations of types - will be most effective in:

a. Commanding the attention of the pilot
b. Producing the proper reaction in the pilot
c. Not disturbing him to the extent of disrupting his skillful performance of other duties.

Our research design conceives a twofold approach to this overall problem. On the one side, we hope to make a "basic approach", isolating the perceptional and reactional fields in the laboratory and carrying out there a point-by-point variation through careful isolation of one variable at a time. On the other side, we hope concurrently to check these "pure research" findings by carrying on a "whole situation approach" in which significant variables will be tested, first in the Link Trainer, under conditions of simulated flying, and later in actual aircraft in flight. We hope thus to make maximum progress and, at the same time, to avoid the unhappy situation of having to extrapolate from simple laboratory situations to the very complicated and fast-moving environment of the airplane pilot.

Let me describe our "Basic Approach" setup very briefly. Our subjects will be given a complicated task, relatively free from learning-effects. As they pursue this complicated task, warning devices of various types will be systematically introduced. The criterion will include such factors as speed of response, correctness and adequacy of response, and absence of interference with the subject's major task.

As it is now set up, the basic task is provided by the SAM Single Dimensional Pursuit Test. The subject sits before a panel board on which appears a reference line and a variable line, the latter being driven up and down by means of a large and irregularly shaped cam. The situation is essentially that of the conventional gyro-horizon, encountered on instrument panels of most aircraft. The subject's task is to keep the variable line on a level with his reference line by fore-and-aft motion of a control-type wheel which he manipulates with his hands. The complexity of the cam suggests that not much learning will occur. Our preliminary checks indicate that, once a brief period of familiarization is past, individual score-levels tend to stabilize. This is further supported by AAF data, indicating satisfactory test-retest reliability for the apparatus.

Our intital runs - for which we are now set up - will consist only of having the subject use his free hand to punch a button when a warning light appears on the panel. From this fundamental approach, many types of variation will suggest themselves at once. We may proceed by increasing the complexity of the light-situation, introducing neutral lights, adding variations in light-pattern, establishing color codes with differential responses, bringing in auditory signals, and so on. We plan thus to attack four major variables:

A. The nature of the warning signal itself
B. The relation of the signal to central and ambient stimuli
C. The setting in which the signal is given
D. The meaning of the warning signal for the subject.

In general, our "whole situation approach" will consist in transferring our findings to the Link Trainer as the subject puts the trainer through normal patterns, with or without rough air and with or without airplane noise. A Stevens noise generator is under order and, as most of you know, will provide noise levels high enough to reproduce the sound spectra in the worst of our modern aircraft. (I presume we can turn the generator off when we wish to reproduce the auditory situation in the P-80!)

It is not anticipated that we shall try for the isolation of variables in the Link that will be enforced in the "Basic Research" approach. It seems probable, indeed, that sooner or later we shall operate with the Link hooked up with all of the present warning devices from some one type of airplane, probably together with some added devices of our own devising.

Two groups of subjects will be employed. One will consist of veteran pilots, now present on the campus in considerable numbers. We can establish our cutting score for experience at almost any reasonable level and still be assured of an ample supply of subjects. A considerable number, by the way, have heard rumors of what we are about to do and have come around to offer their services. Our second group will consist of complete novices - men without any air-time at all. It appears that we shall have little difficulty in obtaining a group well-matched on everything but flight time with our veteran pilot group. We plan to pay all subjects at student rates for their time.

All subjects will be trained to the level of steady performances before research trials begin. In view of the nature of the research, we shall be much interested in spontaneous and invited comments from all of our subjects. If quantitative data and comments accumulate at a reasonable rate, we should have something to report a year from now.

EFFECT OF MODERATE POSITIVE ACCELERATION (G) ON ABILITY TO READ AIRCRAFT-TYPE INSTRUMENT DIALS*

Melvin J. Warrick

*(The following is a summary of the Memorandum Report, TSEAA-694-10, 15 November, 1946, AAF Air Material Command, Engineering Division)

"A study was conducted to determine whether or not a pilot's ability to read aircraft instrument dials is impaired by a positive G force less than that required to produce black out.

"Nine common aircraft instrument dials were reproduced in a printed dial reading test of the true-false type. Thirty-four rated military pilots were given this test on the human centrifuge under conditions of $1\frac{1}{2}$ and of 3G. It was found that the pilots attempted to read as many dials under conditions of 3G as they did under conditions of $1\frac{1}{2}$ G. However, under conditions of 3 G, 24% of their readings were erroneous as compared with 18% under conditions of $1\frac{1}{2}$ G. This increase of errors is statistically significant at the 1 percent level of confidence.

"It is concluded that the ability to read aircraft instrument dials accurately is impaired by a positive G force less than that required to produce black out. It is concluded that further research should be conducted to determine why pilots make more errors in reading aircraft instruments in conditions of increased G, and to determine what factors in the design of aircraft instrument dials can be improved in order to minimize such errors."

Page 42 missing

SUMMARY

PHYSIOLOGICAL FACTORS IN THE VISIBILITY AND LEGIBILITY OF INSTRUMENTS

James C. Peskin
Aero Medical Laboratory
Wright Field, Dayton, Ohio

Although most of the papers being presented here are concerned primarily with a psychological approach to the problems of instrument design, the importance of physiological factors must not be overlooked. Basic data of the intensity discrimination of the eye, visual acuity, and dark adaptation provide the ultimate explanation for many of the phenomena observed in instrument visibility and legibility.

The Vision Unit at the Aero Medical Laboratory is concerned with determining the appropriate physiological data pertinent to instrument legibility. In particular, data are to be obtained defining the intensity threshold and visual acuity and after various short periods of light or dark adaptation. In the reading of instruments, it is common for the pilot to have to glance from his instruments to the world outside the plane and then back to the instruments in fairly rapid alternation. In order to determine the appropriate physiological constants for these conditions, it is necessary for existing data to be recombined so as to provide the appropriate values, or for new data to be obtained.

It is important that research on instruments which begins with a complex of instrument and personnel variables be constantly mindful of possible physiological explanations and existing physiological data. Special attention is drawn to the theroretical work of Hecht and his co-workers in which intensity discrimination, visual acuity, and dark adaptation were shown to be related photo-chemical events.

Page 44 missing

DISCUSSION: Tuesday Afternoon

Mr. Smith asked Mr. Warrick whether the selection of black numerals on white background in his instrument dial tests was made for any particular reason. Mr. Warrick replied that there was no particular reason, except that the test items used were available in black on white form in an existing test.

Dr. Ford asked Dr. S.B. Williams whether he had found that test objects of equal contrast became less visible at higher intensity backgrounds than at lower intensity backgrounds. Dr. Ford reported that he had discovered a situation in which, although photographic methods indicated equal contrast, the performance of the eye was inferior at high intensity levels.

Dr. S.B. Williams reported that it was necessary to divide his experimental data into two parts: At fairly low levels of scope brightness, the phosphor was below its saturation point and the increase in contrast sensitivity was related to increased background brightness. At extremely high brightness, however, the leveling off was partially due to the fact that the phosphor was above its saturation point. In other words, the curve presented from Hopkins included the failure of the cathode ray tube to respond linearly to impressed voltage as well as the change in sensitivity of the eye response. (Because of this, it is difficult to isolate the exact function of either the tube or the eye.)

Mr. Blackwell remarked that decrease in contrast sensitivity at extremely high adaptation levels has been found in controlled visual experimentation since the time of Koenig and Brodhun (1888). Professor Hecht believes the loss of contrast sensitivity to be due to inadequate adaptation at the higher intensity levels. Professor Graham believes the loss in sensitivity to be an artifact related to the dependence of the "critical duration" upon intensity level.

Dr. Marquis querried whether there was a difference in the spectral distribution of emitted light from the scope at different levels of intensity. When Dr. S.B. Williams confirmed the presence of such an effect, Dr. Marquis remarked that the phenomenon reported by Dr. Ford could be due to the differential spectral sensitivity of the photographic emulsion and the human eye.

Dr. Kennedy asked whether any progress had been made on developing a direct tridimensional viewing device for the target in a radar scope.

Commander Dyke reported that several schemes for producing tridimensional viewing of the target of a radar scope had been suggested, and preliminary work completed. In one device, the signal from a radar tube was deflected first to right and then to left by means of a rotating Polaroid in conjunction with a beam splitting system. The difficulty with this system was that a sufficiently precise electrical pickup could not be developed. A second proposition, originating with Sperry-Gyroscope provided a three dimensional picture which could be seen even with one eye. The operator regarded the radar scope through a mirror which moved back and forth.

Dr. Chapanis reported a scheme proposed by the Watson Laboratory in which the position of an aircraft was represented by its position in the interior of a planetarium.

Page 46 missing

LEGIBILITY OF VERBAL AND NUMERICAL MATERIAL UNDER SIMULATED FLIGHT CONDITIONS

John L. Kennedy
Laboratory of Sensory Psychology and Physiology, Tufts College (Army)

I. Introduction

The legibility project at Tufts College has been organized under contract with the Aero-Medical Laboratory, Wright Frield, to determine the effects of typographical factors, vibration, illumination (white light, fluorescent light, red flood lighting, etc.), individual differences, and interactions between these variables as they determine the limits of legibility of tables, graphs, maps, and printed instructions used in an aircraft during flight.

Considerable information on typographical variables in legibility is already available, principally from the work of Tinker and Patterson. Tinker and Patterson (1941) have presented a table of optimal arrangement of typographical factors affecting legibility. Illumination has been studied systematically in relation to visual acuity, adaptation, visibility of different wave-length bands, etc. Vibration, as Dr. Hartline has pointed out, represents a variable about which little is known, either theoretically or practically, in its effects on legibility. There have been several studies of the effect of noise and vibration on motor performance, but these studies have not been directed at legibility. We also believe that further work on the range of individual differences in each of the variables mentioned above will be profitable.

Statistical techniques are now available for measuring the degree of interaction between these variables. We propose to utilize the analysis of variance methods to determine whether, for example, frequency of vibration alone is effective or frequency of vibration plus amplitude of vibration is responsible for variation in legibility when the material is vibrated.

Progress in this project has been limited to the construction and arrangement of apparatus which will control the above variables. We are just starting a pilot experiment on vibration amplitude, illumination, and individual differences. The remainder of this paper will describe the apparatus and tests which have been prepared for this experiment.

II. Apparatus

A. The Vibrometer is a device for vibrating the visual field at known frequencies and amplitudes. Some preliminary work on mechanical devices for vibrating stimulus material demonstrated that it is difficult to obtain uniform vibration of a large surface. With the assistance of the Electrodyne Company of Boston, we have prepared an optical device, which produces simple harmonic motion of the visual field optically rather than mechanically. The apparatus as it stands, somewhat limits head movements on the part of the subject but

otherwise appears to be suitable, reliable, and valid for our purposes. The knobs and scales on the top of the instrument allow continuous adjustment of desired amplitude of vibration between .25 and .005 inch with frequency continuously variable from 0 to 3000 d. v./min. The direction of motion of the visual field may be varied in any angle from vertical to horizontal motion, or the visual field may be given a circular or eliptical motion. Motion is produced by two pairs of Risley rotary prisms, rotating in opposite directions. Amplitude is controlled by the degree of angular displacement of the two prisms of a pair, frequency by speed of rotation of the whole system.

The following experimental arrangement is now being used. The subject is positioned with his eyes at the level of the center of the prisms. Below the vibrometer are two telegraph keys, S and D, which the subject uses in responding. His responses are recorded on an ink-writing polygraph by means of a two-way marker. The stimulus material, now consists of lists of paired numerals, to which the subject responds as "same" or "different". If he perceives the pair as same, he presses the S key, if different, he presses the D key. By this technique, we hope to determine the legibility of single numerals and groups of numerals such as are found in tables and graphs. Samples of stimulus material printed in 11 point type have been distributed. Each test consists of 180 pairs of single digits arranged in 9 columns of 20 each. All digits from 0-9 are used. An equal number of "same" and "different" responses are required on each test. The sequency of pairs was randomized in the test. We hope to have available shortly a library of test material made up of these tests printed in several type styles, type sizes, and marginal formats.

Illumination of the test stimuli is variable from 1 to 15 foot candles. General room illumination is also variable between these limits. Red flood lighting of the stimulus material may be effected by placing appropriate filters in the light sources. Provision is also made for ultra-violet illumination of fluorescent printed material using standard Air Force ultra-violet sources.

III. Legibility of Fluorescent Materials.

One possible practical application of legibility research conducted previously should be mentioned in closing. We have obtained samples of fluorescent printed materials now used. Tables and verbal material to be read under ultra-violet are often printed so that the reading matter fluoresces on a black background. One of the largest differences in legibility discovered by Tinker and Patterson was between white on black and the usual black on white type of page. A positive is much more legible than a negative under the conditions of their experiments. Their results suggest that, for preparation of fluorescent tables and graphs, the numerals and letters be printed in black ink on a fluorescent background. If dark adaptation level is affected adversely by thus increasing the general illumination level of the page, it may be possible to find a red fluorescent ink which will emit principally in the red wave-lengths under ultra-violet and still present a satisfactorily legible condition for reading under normal daylight. A sample of such a preparation is presented. In this particular sample, the spectro-photometric curve of the red fluorescent ink has not yet been determined.

DESIGN FACTORS AFFECTING THE LEGIBILITY AND INTERPRETABILITY OF INSTRUMENT DIALS AND SCALES

W.M. Smith
Princeton University (Army)

INTRODUCTION

In the initial phase of our work at Princeton, we have been concerned with a comprehensive review of the general literature encompassing the use and evaluation of devices and materials employed to present information visually to pilots and other aircrew personnel. The review necessitated exploring and tapping numerous sources, among which were, principally: the files of the Medical Research Division of the National Research Council, the Office of Research and Invention of the Navy Department, the Royal Air Force Delegation, and other similar organizations. Previously organized bibliographic sources were consulted for all possible pertinent references, and with such leads, the above-mentioned files were entered in order to refer to original articles, and thus obtain direct information on the nature and results of tests used in evaluating the design characteristics of various "visual information presenting devices".

It is not our purpose here to consider the detailed experimental results of the survey, but a few general facts are noteworthy.

In the first place, our review showed, as many of you have yourselves discovered or suspected, that computers, warning devices, maps, tables, etc., have received negligible experimental attention in the past. Secondly, despite the fact that a somewhat extended experimental evaluation of instruments themselves has been made, the factor of illumination is the one which has received the most concentrated study. This study, of course, was carried on in many laboratories and, in each, at the expense of other important design considerations.

Considered as a group, the studies of instrument design have been approached from two different points of view. In the one case, as illustrated in the experiments conducted by Loucks, the approach was specific in nature, i.e., comparative evaluation was made of varied designs for dials now utilized on the typical aircraft panel. Illustrating the other avenue of approach, we might cite here the more recent work of Vernon at the Psychological Laboratory at Cambridge. In this case, the approach to the problem was general in nature. The research was concerned with a determination of scale design characteristics without regard to specific utilization of any particular dial or instrument. The study at Princeton will be of the general type. We have structured the experimental design accordingly.

EXPERIMENTAL APPROACH

The Princeton directive, broadly stated, suggests the investigation of any and all scale design variables. Many such variables can be enumerated:

(1) frequency of gradations, (2) thickness of gradations, (3) length of gradations, (4) size of numbers, (5) black on white--white on black, (6) frequency of numbered divisions, (7) shape, width, length of pointer, (8) location of pointer, (9) size of scale or dial, (10) size of smallest division, (11) value of number system utilized --- 0-10-20---, 0-20-40---, etc.

The experimental handling of these variables at once raises the question of their interaction. It is not known at present the significance of interaction factors in the reading of instruments. If the interactions are zero, the variables under consideration can be investigated singly; however, if any interactions are significantly different from zero, the variables concerned require handling as a set. Thus, one of the present problems being investigated at Princeton is that of variable interaction in scale design. By the simultaneous manipulation of several variables, we hope to get satisfactory measures of the interaction factors.

Another problem which is of important concern in planning the research is that of error frequency. Normally the incidence of error in scale reading is small. This makes the statistical discrimination between different designs somewhat difficult. Either the number of readings must be increased to make error scores very reliable, or the experimental conditions must be varied to augment the frequency of error. Our present preference at Princeton is to improve significance tests by utilizing large numbers of trials, rather than by shortening reading time, tightening the criterion of error or otherwise increasing error frequency.

Estimates of error frequency have been obtained from a few previous investigations. Vernon, in his study of dial and scale reading, found the error frequency to be between 1.5 and 9.6 percent. Some Field Artillery data indicate the same general incidence of scale reading errors - from 3.3 percent on one type of instrument to 6.8 percent on another. Error frequency on counter-type mechanisms evidenced error of the order of about 2 percent. This latter figure approximates the error frequency found by Chapanis in his study on the comparison of conventional radar bearing and range dials and direct-reading counter-type indicators. Here the error frequency for the experimental counter-type indicator was 3.5 percent. Error frequency on four standard radar bearing and range dials was between 8 and 14 percent. In any event, discrimination between two conditions with error frequencies in the range indicated by the data above will require many, many trials.

INITIAL STAGE OF RESEARCH

With the foregoing considerations in mind, the work at Princeton is presently concerned with the investigation of 6 variables; (1) number of units effectively represented on a scale (i.e. 100,200,400,600), (2) number of gradations (i.e. at 10's, 5's, or units), (3) shape of pointer (blunt versus thin on dials), (4) size of dial - 2 3/4 inches versus $1\frac{1}{2}$ inches diameter), (5) vertical versus circular scales, and (6) level of illumination.

Although the differences between circular and vertical scales are primarily of academic interest, it is believed that some systematic information is needed on this point and that it may serve as a springboard for investigations to be undertaken in the future. It is understood that Vernon and Brown in Britain are currently carrying out similar experiments on round versus straight scales.

A brief description of the experimental situation we are employing is as follows: Two sets of nine scales, one circular and one vertical, have been constructed. The circular scales have been reduced photographically so that they approximate normal and half-normal instrument size. The vertical scales have also been reduced appropriately so that their length equals the circumference of the corresponding scales. In other characteristics, number of gradations, width of gradations, unit values, etc., the two sets of scales are equivalent. For experimental presentation the circular scales will be mounted on cards, approximately 11 by 14 inches, in three banks of four each. Each exposure card will contain 12 scales and all of these will be of the same kind but each will show a different setting. The same procedure will hold for the vertical scales, except that the exposure field will necessarily be larger in order to accommodate the bank of 12 scales. The exposure cards will be presented in a simulated cockpit arrangement, approximately 28 inches from the subject's eyes and with the top of the card depressed 15 degrees from the subject's horizontal line of sight. The subject will have before him a series of exposure cards which he will read in sequence as they are presented. The first card will be a familiarization one, a scale without a pointer. It will be a replica of the kind of scale to appear on the first test card. When the experimenter exposes the first test card to be read, the subject reads the 12 scales one by one, each to the nearest unit, and writes down his readings. As he records his 12th reading he presses a button to stop a timer which records his reading time for the card. The next card in the series is a new familiarization card, then a test card, and so on. The experiment proceeds with the subject reading and the experimenter timing the performance for each test card. By means of a special arrangement on the writing surface, it will be unnecessary for the subject to divert his attention from the stimulus field at any time. He will space his written numbers with the aid of a notched guide so that he can record his readings without looking at the writing surface.

Subjects will be tested in groups of 4 or 5. The subject population will be comprised of high school and college students, excluding so far as is possible, those who have had any special experience with this sort of perceptual material. Tentative plans call for the use of some 20 subjects.

The foregoing presents briefly and in general the scope and initial program of the Princeton study concerning the determination of optimal design characteristics of dials and scales. At present the work is still in the planning and preparatory stages. Master dials and scales have been drawn and are now being photographically reproduced preliminary to the construction of the test cards.

VISUAL FACTORS IN DIAL AND SCALE DESIGN

Purdue Research Foundation (Navy)
Joint Research Program

The Purdue - Navy Research program was set up to study the general problem of instrument dial design. There are many factors to be investigated before specifications for dial design and construction can be drawn up. The purpose of this program is to determine the effects of several of these factors. These are three studies in progress at the present time. These concern:

(1) the effects of dial shape on legibility of the dial, being conducted by R.B. Sleight

(2) the effects of numeral design on legibility of numerals, being conducted by J.G. Gleason

(3) the effects of brightness-contrast between task areas and surrounding areas, being conducted by E.E. Dudek

These studies are supervised by Dr. J.A. Bromer.

Project No. 1 - R.B. Sleight

The purpose of this project is to determine the effects of dial shape on legibility of the dial.

The immediate problem is to determine, by objective measurements, the differences in speed and accuracy which will result from reading and interpreting information from dials of the following shapes: round, vertical, open-window, quadrant, and horizontal.

The equipment which will be used includes a ground-glass screen which has been fitted into a frame so that the center of the screen is at eye-level height for a seated subject. (Slides depicting the various dial types will be projected tachistoscopically on this screen.) Two projectors, with tachistoscopic shutters, are being connected in series with a pendulum chronoscope, so that they will alternately illuminate the task area on the screen and keep this area at a constant brightness throughout the experiment. One projector covers the task area with this standard brightness between exposure trials to keep the subject light-adapted. Before each exposure a warning buzzer sounds and two seconds later, the first projector cuts off and, at the same time, the task material is projected for the desired exposure time by means of the other projector. (Limits of exposure time will be about .1 to 1 second.) After each exposure, the first projector again flashes on the screen to maintain the standard task area brightness.

The materials to be used consist of twenty-five slides of each dial shape. These slides were prepared from photographs of scale drawings of the various dial types. The pointer settings for each type of dial were arranged in predetermined order, such that, an equal number of settings occurs in various areas on the dials. The factors of: numeral dimension, size of graduation, distance between graduations, dimensions of the pointers, amount of a graduation

mark covered by a pointer, and the position of the numerals relative to the scale boundary, were all held constant on all slides, thus making the dial shape the only dependent variable.

The procedure will be as follows: The subject will be seated about three feet in front of the ground-glass screen, upon which the dial faces will be projected from the rear (that is, the side opposite that which the subject faces). The series of slides will be projected in a predetermined random order for each subject. The accuracy of readings made on each type of dial will be compared.

It is hoped that the results of this study will suggest the type or types of dial shapes best adapted to general dial design.

Project No. 2 - J.G. Gleason

The purpose of this project is to determine the most legible numeral design. Separate investigations are proposed to determine the effects on legibility of: (1) the ratio of width of numeral stroke to height of the numeral, (2) numeral font design, and (3) the use of italics.

In attacking the first of these problems, a Clason Acuity Meter will be used to project upon a ground-glass screen numerals drawn with varying height-width stroke ratios. Slides depicting height-width ratios between 1 to 16 and 1 to 3.3 will be projected.

Subjects will be asked to read the numerals presented on these slides. Two procedures will be used: (1) the size threshold of visibility will be determined for each height-width ratio. In this case, the most legible ratio is the one which provides the minimum threshold size. (2) The speed and accuracy of apprehension of groups of digits for these various ratios will be determined by tachistoscopic exposure. In this case, the height-width ratio providing the most rapid and accurate apprehension will be termed the most legible. The factors of over-all size, color contrast, brightness contrast, and illumination, which have been studied and reported upon by other investigators, will be controlled.

The findings of this first study will be used in the design of succeeding studies dealing with the effects on legibility of italics and general numeral style.

Project No. 3 - E.E. Dudek

The purpose of this study is to investigate the effects of brightness-contrast on visual performance. The brightness of three separate areas will be considered: The "task area" falls within a central cone of vision with a maximum radius of about 10°. The "surround" includes the area adjacent to the task area. It may be compared to the radar console or to the surface of a machine at which an individual works. The "background" refers to the general area surrounding the operator on all sides in the visual periphery, and usually at a greater distance from him than either the task or the surround.

Three separate investigations are planned: (1) to determine the effects of size of the surround on visual acuity, and to determine an optimum size of surround, (2) to determine the effects of the contrast between brightness of the surround and of the task area on visual performance, and (3) to determine the effects of brightness of the background in relation to the brightness of the task area.

For the first study, to determine the effects of size of surround, a ground-glass screen illuminated from behind will be used. Cardboard shields will be used to vary the size of the surround on this screen. A graded series of these shields has been prepared with central openings providing surrounds with radii from 10° to 45o of visual arc. Additional sizes will be introduced above 45° if necessary. These sheets can be interchanged behind the glass screen to limit and vary the size of the illuminated spot or "surround" to which the subject will be exposed.

The subject will sit facing the screen (eye to screen distance of 15 inches). The stimulus, a checkerboard figure, (similar to that in the Bausch and Lomb orthorater), will be projected on the screen from the rear (side opposite that which the subject faces). Acuity will be measured in terms of the smallest checkerboard (detail) perceived under conditions of varying sizes of surround. Two different brightness levels of background will be used initially (about .5 and 50 foot lamberts respectively), and, if significant differences are found under these two conditions, additional intermediate brightness levels of background will be used to determine their relative effects. Different task materials, such as, a series of digits projected tachistoscopically to measure span of apprehension, and a spot of light (similar to a radar "blip") with which a pointer must be alined, will also be used under the same conditions.

Materials have been ordered for two other experiments on brightness-contrast between surround and background and task area. Plans are to construct a box-like compartment of white, translucent, Plexiglas panels. These panels will be illuminated from the rear by means of incandescent lamps. It is planned to vary the brightness of the task, surround, and background areas between the approximate limits of .5 and 50 foot lamberts. The task materials will be projected, in a manner similar to that proposed in the first experiment, from the rear of a ground-glass screen, which will be set in the center of the front Plexiglas panel. The effects on visual performance of different combinations of task, surround, and background brightness will be determined.

To summarize, it is the aim of these studies to determine some of the factors that may be generally applicable to the design and illumination of instrument dials. Throughout, we are attempting to determine those principles which will have the broadest general application.

THE RELATIVE EFFICIENCY OF DIRECT-READING COUNTERS AND SCALES FOR TARGET INDICATION FROM RADAR EQUIPMENT[1]

A. Chapanis
Systems Research Field Laboratory
The Johns Hopkins University

The Cathode-ray tube (PPI or Plan Position Indicator) in a piece of radar equipment is a display screen upon which are accurately represented the positions of a number of targets in space. It is an essential part of the radar operator's task to convert, as rapidly and precisely as he can, the positions of target "pips" appearing on the face of such a screen into actual bearings and ranges. A considerable proportion of the time delay and errors normally occurring in this conversion process can be attributed to the difficulty of reading the scales and dials furnished with the radar equipment for this purpose. This paper summarizes the results of two experiments undertaken to explore the relative advantages of direct-reading counters and scales in this application.

EXPERIMENT 1[2]

In a typical search radar or remote radar indicator, the bearing of a target is read from an annular bearing scale around the PPI ("D" in Figure 1). A bearing cursor can be aligned manually with a target "pip" appearing on the face of the PPI, and the intersection of the cursor line with the scale is read to give the target bearing. Ranges on the radar equipment studied here are read directly from counter-type indicators similar to "B" and "C" in Figure 1.

In the first experiment a "bread-board" model of a direct-reading bearing and range indicator similar to "A" and "B" in Figure 1 was constructed, and the speed of reading bearings and ranges from this instrument was compared with the speed of reading target information from four standard radar units. Five subjects each were tested with a total of 50 randomized target settings on each equipment - a total of 1,250 observations for all subjects and all pieces of equipment.

The following procedure was used: Before each trial, the subject absented himself from the instrument while the experimenter set in a bearing and range. The PPI scope (or bearing counter) and range dials were then obscured by a large

---

1. The research described in this paper was performed on Contract N5-ori-166, Task Order 1, between the Special Devices Center, Office of Naval Research, and The Johns Hopkins University.

2. The results of this experiment have been previously reported (Chapanis, A.: Speed of reading target information from a direct-reading, counter-type indicator versus conventional radar bearing-and-range dials. Systems Research Field Laboratory, The Johns Hopkins University, Jamestown, Rhode Island, Memorandum Report No. 166-1-3. 1 November 1946. 12 pages. (Restricted)); the results of the second experiment, described later, have not been previously reported.

piece of cardboard. The subject returned to the equipment, stationed himself in the normal operating position and awaited a signal from the experimenter. The experimenter called "ready", and shortly thereafter quickly removed the covering piece of cardboard and simultaneously pressed the starting mechanism of the stopwatch. As soon as the subject had finished calling off the bearing and range, the experimenter stopped the watch and recorded the time. A recorder wrote down the bearing and range called out by the subject. When this sequence was completed, the subject again absented himself from the equipment while the experimenter set in another bearing and range for the next test sequence.

The times required to read bearing and range information from the various units are shown graphically in Figure 2. Briefly, it was found that the average time required to read a single bearing and range from the standard equipment is about 3.4 seconds, and that the average reading times on the standard units do not differ significantly from each other. The average time required to read target information from the experimental dials, however, is 1.8 seconds which amounts to a 47% saving in time.

The numbers of errors made in reading bearing information are shown in Figure 3. Marked differences in accuracy were found in the reading of targets from the various pieces of equipment. The experimental counters were by far the best and the SR radar the poorest in this respect. Errors on the SG radar and the VF and VJ remotes occur about equally often and are more than three times as common as on the experimental dials. Bearing errors in the readings from the radar equipment were more than seven times as common as range errors. Since the ranges are read from counter-type indicators in all cases, this is further evidence of the superiority of the direct-reading type of indicator.

EXPERIMENT 2

The first experiment, it should be clearly recognized, was an elementary approach to the problem of designing scales for presenting target information, in the sense that it took an isolated portion of a work-task out of its normal position in a sequence of operations and analyzed performance on this segment of behavior. For this reason, there may have been some interaction effects which would change the magnitudes of the difference found. As an illustration, the operator normally cranks the bearing cursor around to a target and has, therefore, a general idea of the bearing before he looks at the scale. In this experiment, the operator's task was considerably more difficult since he was required to hunt for the bearing cursor line before he could read a bearing.

In order to determine whether the experimental, direct-reading counters would be more efficient when installed on a piece of radar equipment, the second experiment was performed under more realistic conditions.

It may be pointed out parenthetically that the construction of a direct-reading, counter-type, bearing indicator for this experiment presented a fairly difficult mechanical task. The reason for the difficulty is that the counter reads from 000° through 359° and then to 000° again. Further, it is necessary that the

counter work forward and backward. Finally, the last digit of such a counter must operate in a sequence of 0 to 9, 0 to 9, 0 to 9, and 0 to 9; the second digit operates from 0 to 9, 0 to 9, 0 to 9, and 0 to 5; while the first digit operates from 0 to 3 and then repeats. The design and construction of this counter[4] (shown as "A" in Figure 1) will be described in detail in a later report.

This experiment was designed such that four subjects operated the VJ remote indicator shown in Figure 1 to obtain the bearing and range of targets which appeared one at a time on the PPI. In half of the trials, the subjects read the bearings from the bearing scale ("D") and in the remainder of the trials from the bearing counter ("A"). The positions of the targets and the order of the various trials were suitably randomized. A total of 160 observations were made.

The results of this experiment show that, on the average, a radar operator requires about 12.8 seconds to locate a target, operate the bearing and range cranks, and read the bearing scale and range counter. With the bearing counter replacing the bearing scale, the average time for performing the same operation is reduced to 11.1 seconds - a saving of 1.7 seconds per target. This difference of 1.7 seconds in favor of the bearing counter agrees exactly with the difference between the reading time with the experimental counters and the scales on the VJ remote indicator in Experiment 1.

Since only a small number of targets was tested under the two conditions, it is difficult to determine whether the bearing counter is inherently more accurate than the bearing dial in this experiment since the error measurements are complicated by the normal operating errors made by the subjects, e.g., errors in aligning the bearing cursur with the target. It is interesting to note, however, that there were 3 serious errors, i.e., obvious misreading errors greater than 3°, out of 80 observations with the bearing scale, and only 1 such error out of 80 with the bearing counter.

CONCLUSIONS

It is concluded from the results of these two experiments that the use of a direct-reading, counter-type bearing indicator is superior to the conventional circular bearing scale for target indication purposes.

4. By Mr. William Hamilton at the Systems Research Field Laboratory.

FIGURE 1

Top View of a VJ Remote Indicator showing the Direct-Reading Bearing Counter (A); an Experimental Placement of the Range Counters (B); the Conventionally Located Range Counters (C); and the Bearing Scale (D). The Operator's Bearing and Range Controls are in the Lower Left- and Right-Hand Corners, respectively.

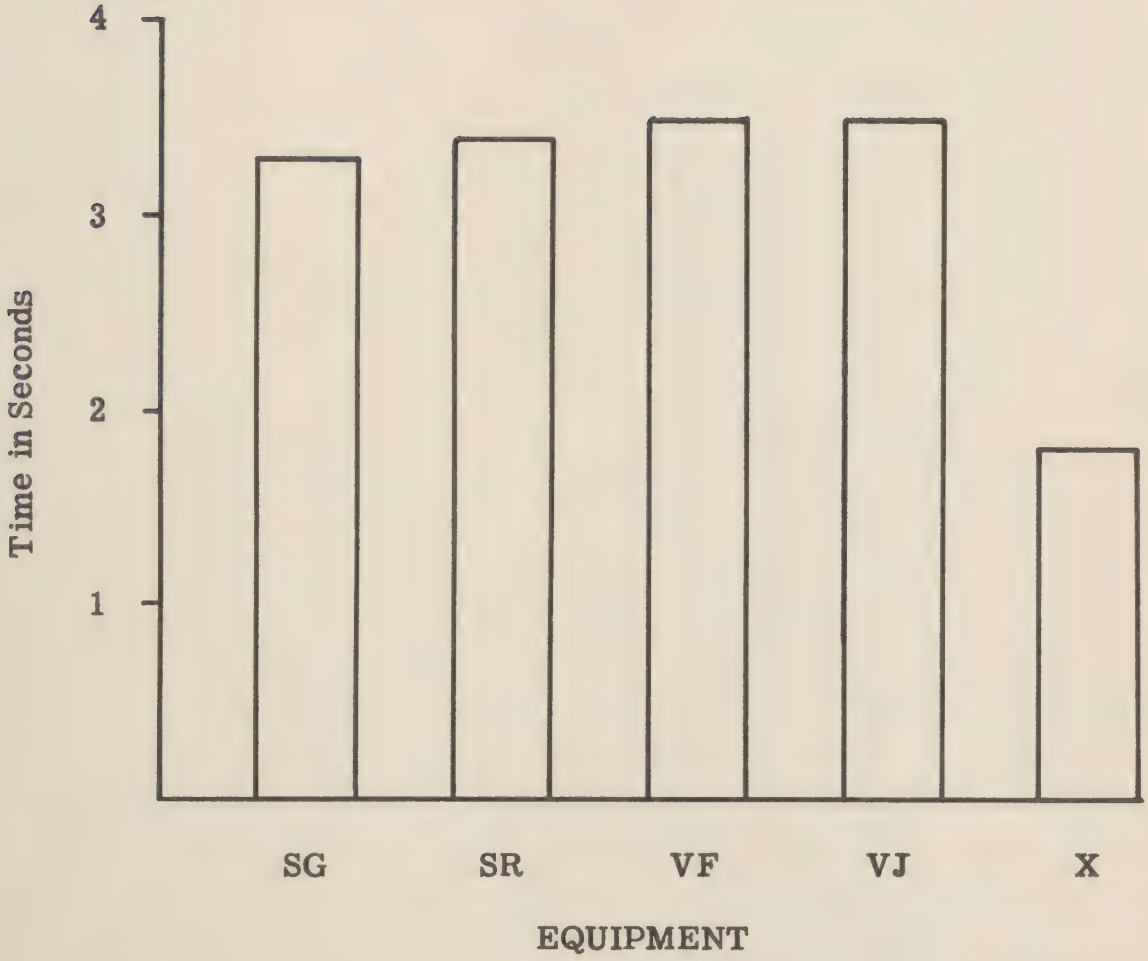

FIGURE 2

Average Times Required by Five Operators to Read Bearing and Range Information from Four Standard Radar Units and from Experimental Bearing and Range Counters (X).

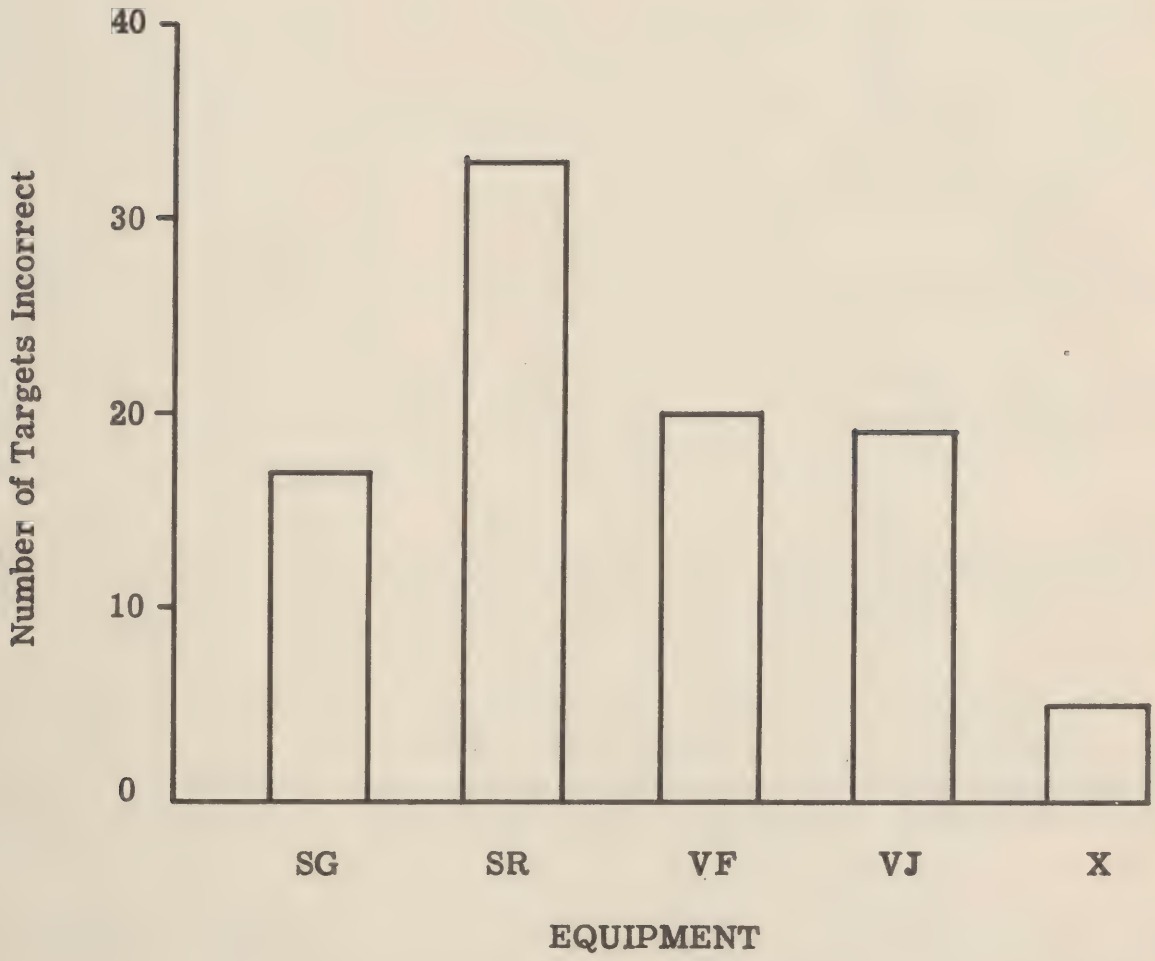

FIGURE 3

Total Number of Bearing Errors Made by Five Operators in Reading 250 Target Settings from Four Standard Radar Units and from Experimental Bearing and Range Counters (X).

DESIGN OF SCALES FOR AIR NAVIGATION PLOTTERS

J.M. Christensen
Aero Medical Laboratory, Wright Field

I. Introduction.

Several investigators have pointed out, and most navigation experts agree, that one of the chief causes of errors in aerial navigation is the misreading of the seemingly simple dials, tables, and scales the navigator must use. Research Bulletin 45-36, published by the AAF Training Command, points out that errors in the use of the air navigation plotter sometimes run as high as 31%. A number of errors on a simple navigation instrument leads us to suspect that something may be wrong with the basic design of that instrument as the navigators who use them are a carefully selected group of capable individuals. We cannot expect to get much better material for navigators, so this leaves us with only two alternatives if we wish to improve any aerial navigation - better training and better equipment. This project I am about to describe is an attempt to improve one of the navigator's simplest but most frequently used instruments - his aircraft plotter. The plotter is used for measuring courses, plotting courses, plotting celestial lines of position, radio and radar lines of position and any problem involving measurement of angles and plotting of lines or vectors. (Demonstrate its use.)

Any indicated change comes at a particularly opportune time, as the presently used plotter will need to be revised now that the Air Corps is converting from use of the statute miles system to the nautical miles system.

II. Statement of Problem.

Plotters have an azimuth scale and a straight edge. These elements can be presented in a number of ways. This study was concerned with the effect of variations in design of basic plotter elements on numbers and types of errors made with the instrument.

III. Research Procedure.

A. Errors can be divided into two general classes - errors of measurement and errors of plotting. The first class includes those errors the individual makes when measuring a line or vector that has already been plotted. Plotting errors include those made when plotting a line or vector of a specified number of degrees.

Each of the above classes may be divided also into specific classes - reciprocal, reversal, reference, tolerance, and miscellaneous errors. These first four classifications (i.e., excluding miscellaneous) include 92% of the errors made.

A reciprocal error is defined as that type in which the navigator reads the value of a measured or plotted line exactly 180° in error. It is apparent from examination of any of the plotters that the reason for this type of error is the fact that each position on the protractor element is shared by two values 180° apart.

A reversal error is defined as that type in which the navigator reads the wrong direction from a numbered graduation. For example, if the navigator wished to plot a value of 93°, he would make a reversal error if he read three degrees in the wrong direction from the 90° mark and plotted a course of 87°.

A reference error is defined as that type in which the navigator measures or plots a course using East or West instead of North as the zero reference. The result is, of course, always 90° or 270° in error.

A tolerance error is defined as that type in which the navigator reads a few degrees in error either because of carelessness or inability to read the scale with the required accuracy. A tolerance of one degree on either side of the correct answer was allowed.

Miscellaneous errors included such types as reading 226 for 266, using the plotter wrong face up, and confusion of inverted numbers, such as 3 and 5, 6 and 9, etc.

Using these classifications of errors, we were able to classify about 97 percent of all errors. The 3 percent unclassifiable were included with the miscellaneous errors.

B. Six plotters were constructed in order that four basic comparisons might be made. All the experimental plotters were identical with respect to such elements as figure size, figure style, protractor size, and grommet size. The models used in comparing two plotters are identical except for the fact that one has two edges and the other has one edge. The thought was that errors might be reduced by use of a double-edged plotter as it is never necessary to invert such a plotter when measuring a course near the top of the chart. It becomes necessary when using a single-edged plotter under the same circumstances to invert the plotter in order to get the straight edge along the desired line or vector. When inverted, all scales must be read upside down and in a direction opposite to that employed when the plotter is in the normal position. This would seem to lead to reversal errors.

The second slide shows the models used in comparing a left-right scale with a right-left scale. It would seem that the left-right scale would produce less reversal errors as most figures, tables, and other literature with which we deal are read from left to right. The left-right reading habit is felt to be rather basic.

The third slide shows the models used in comparing a plotter having the scale graduations numbered every 5° with another plotter having the scale graduations numbered every 10°. It was thought that the numbering of the five degree graduation marks would assist in the reduction of reversal errors. This proved to be the case.

The fourth slide shows the models used in comparing a plotter having one protractor element with a plotter having two protractor elements. One element was set 180° in azimuth from the other. Thus, one set of figures would appear right side up regardless of the position of the plotter. The reading on one protractor element should serve as a check on the other. However, the added protractor had not only a deleterious effect on accuracy, but also slowed the subjects significantly.

C. It was essential that the models be administered to a naive sample, as the previous experience of navigators with plotters would be difficult, if not impossible, to control. Permission was obtained to use 350 advanced mathematics students from Dayton high schools for the experiment. They were taught and tested in such order that no advantage would accrue to any plotter model.

D. The test consisted of 23 measurement and 23 plotting problems. One half the items were solved on a copy of a Mercator Chart, and the other half were solved on a chart similar to a Lambert-Conformal. Alternate forms of each test were constructed.

IV. Findings.

A. Error Breakdown

A breakdown of errors into the general categories of "measurement" and "plotting" disclosed that 55 percent of all errors were errors in measurement, and 45 percent of all errors were errors in plotting. I will say more about this later.

A specific breakdown of errors shows that 32 percent of all errors were reciprocal errors, 30 percent were tolerance errors, 22 percent were reversal errors, and 8 percent were miscellaneous errors. Thus, we see that 84 percent of all plotter errors can be classified into three specific groups. This is fortunate for us who hope to do something about reducing the number of plotter errors.

B. Several significant facts were noted about the reciprocal errors (remember that almost 1/3 of the total errors were of this type.) There were 755 reciprocal errors made, and of these 631, or 85 percent, were made on measurement problems as opposed to only 15 percent on plotting problems. The meaning of this is not clear, but I propose that it has something to do with the comparative simplicity of measurement and plotting. Measurement of a line or vector is simplicity itself for a navigator. It soon becomes highly automatic, and hence, the navigator, not thinking, probably takes the most convenient scale readingas the correct answer.

This would indicate a preference for the outer scale. Analysis revealed that experienced navigators made erroneous reference to the outer instead of the inner scale by a ratio of 2.6 : 1.00, whereas the less experienced and probably more cautious high school advanced mathematics students had a preference of only 1.21 : 1.00 for the outer over the inner scale.

Plotting required more active participation on the part of the navigator. Presumably he knows the general direction a line will take before he ever puts his plotter on the chart.

C. No detailed analysis was made of the relative speed with which the subjects could use the various models, it was felt that speed is of no practical importance in this task when the all-important factor of obtaining a correct answer is considered. However, sufficient analysis was made of speed to assure us that in all cases the design used with the greatest speed was also as good or better from the standpoint of accuracy. The median correlation between speed and number of errors was -.30.

D. Another important source of general error involves the measurement or plotting of courses near 180° or 360°; that is, problems near a meridian. It is difficult to manipulate the plotter so as to measure or plot those courses that are nearly parallel to a meridian. The incidence of error for all lines or vectors within 10 percent of a meridian was 21 percent. It is also interesting to note that although only 130 of the 24,283 problems were omitted, 62 or 48.7 percent were of this type. Yet only about 16 percent of the total problems attempted were of this type.

E. With regard to the four basic comparisons mentioned earlier it was found that the double-edged plotter was significantly better than the single-edged plotter. The single protractor element plotter was better than the double protractor element plotter, the left-right scale plotter was slightly better than the right-left scale plotter, although the "p" value did not reach the 5 percent level of significance. Further research is planned on this point. The five degree scale was slightly better than the ten degree scale, although the "p" value was only .18.

Incidental findings include the fact that a flat-topped 3 and a 5 when inverted are often confused. The subjects also used the plotter wrong face up quite often.

V. Features of Revised Plotter

As a result of this experiment, we have designed a plotter that we believe combines features that will tend to decrease the various types of errors.

You will notice that it has a double edge, a single protractor element, a left-right scale, and graduation marks numbered every 10 degrees. This last item requires explanation as you may recall that the experimental data indicated that a scale with the protractor graduations numbered every 5 degrees tended to reduce reversal errors. However, although it was possible to place digits every five degrees on the experimental models it was later felt that it would be undesirable to do so on any model intended for use in the air. Because of the vibration and frequently poor illumination, it is believed essential that the figures be relatively large when the instrument is to be used in the air.

To compensate for the loss of this experimentally desirable feature, we employed what we term a "staircase" scale effect. With this, you will notice, the length of the graduation marks increases as the units digit increases. Thus, it is hoped that an individual would soon learn that as he "goes up the stairs," so to speak, the number must increase, and as he goes down the stairs, the number must decrease. The odd five degree graduations are uniquely marked to enable easy recognition.

I previously mentioned the problem involved in working with courses nearly parallel to a meridian. To handle these, we have added a partial scale, which we call a 90° offset scale. It automatically does for the navigator what most of them have tried to do in their heads until now, that is, add or subtract 90° to what they obtain by measuring such courses from a parallel of latitude instead of a meridian of longitude. The possibility of extending this partial scale through 360° is being considered. We believe it could be arranged so that celestial navigators could plot celestial lines of position without first plotting the azimuth line.

The use of a double-edged plotter has another advantage. It enables the use of a larger protractor element without increasing the overall width of the instrument. This results in another advantage - the use of larger figures.

This plotter offers as a partial solution to the problem of reciprocal errors the scale presentation you see here. The complete solution, however, lies with the operator. A competent navigator should have an idea of a line's direction before he measures or plots. For example, if he is heading north and the wind is drifting his airplane to the right, he should recognize a wind vector in the neighborhood of 90° as erroneous. Similarly, if he is heading in a northerly direction he cannot accept a course in the neighborhood of 180° as correct. By combining the two sets of graduations into one scale the user must in each case choose one of the two available readings for his correct answer. It is an attempt to force the navigator to make a deliberate choice. Further research is needed on this feature.

This plotter will have adhered to it two small knobs. These will prevent the navigator from using the plotter wrong face up.

It is also calibrated in nautical miles, as this is the system of distance measurement to be used in the future in the Air Corps.

VI. Future Research.

The results of this study suggested several other aspects of general and specific application.

One of these involves the staircase scale. We need to discover whether or not, for example, a staircase scale will reduce reversal errors, or whether or not the staircase scale, when used with a right-left scale, will overcome the reversal error tendency of the ordinary right-left scale. An experiment has been designed for this project.

Further research is needed on the offset scale and its extension to problems involving the plotting of celestial lines of positions.

The legibility of various styles of numbers and perhaps letters when inverted is another problem. On many of the navigator's instruments it is often necessary to read figures upside down. There must be a particular design that is more legible than other designs when read in the inverted position.

The effect of vibration on legibility and size of numbers is being attacked under our contract with Tufts College. The results will be welcomed for use on this plotter design.

As far as the plotter goes, the Equipment Laboratory is cooperating with us in the service test of them. We plan to do at least one independent study using a population of plotter-naive college students.

INSTRUMENT LEGIBILITY AS A FUNCTION OF DIAL SIZE AND SPACE OF SCALE DIVISIONS

A.C. Williams, Jr.
University of Illinois

Walter Grether
Aero Medical Laboratory
Wright Field

In the design of aircraft instruments the legibility of the instrument dial is an important consideration to the personnel using the instrument. It is desirable to design the dial so that it is easily legible, at least to the limits of reading accuracy required by the nature and function of the instrument. Legibility depends upon a number of factors, but this experiment is concerned with only three of them--the size of the dial, the angular separation between its scale markings, and the illumination in terms of the contrast between night-time and daytime conditions.

In order to study how size, angular separation, and illumination affect legibility sixteen experimental dials were constructed. These sixteen included four different sizes and four different degrees of angular distance between subdivisions. But all dials were alike in that their full scale read from 0 to 50 with unnumbered marks subdividing the scale into tens. The relationship between size and angular separation as incorporated in the dials can be seen from Figure 1. Disregarding for the moment the numbers in the table, then each box represents a dial. The size (diameter) of the dial is given by the row designation, the angular distance between subdivisions by the column designation.

As a test of legibility it was decided to use the speed and accuracy with which the dials could be read, and to obtain these measures under two conditions of illumination, simulated daylight and simulated nighttime. An apparatus was constructed for presenting the dials to subjects for reading. They were presented from behind a shutter in a screen. When the shutter was opened, a dial was exposed with its pointer set to some reading. When the subject responded the shutter was closed. The difference, if any, between the response and the actual setting was taken as the error of reading; the time during which the shutter remained open was taken as the time of reading (automatically recorded). Daytime conditions were simulated by illuminating with a fluorescent tube; nighttime was simulated by illuminating with a standard aircraft ultra-violet instrument light. The dials were marked with fluorescent paint. We used eighty subjects, each making eighty readings so that eventually every dial was read 400 times; 200 daytime, 200 nighttime. The settings chosen represented equally all portions of the dial and the order of presentation was randomized.

For each dial four frequency distributions were made. These were: (1) distribution of errors, nighttime, (2) distribution of errors, daytime, (3) distribution of times, nighttime, (4) distribution of times, daytime. We will first consider the errors. Errors were tallied without regard for sign, all errors being considered positive. This resulted in distributions skewed to the low end with a suggestion of bimodality at the high end. Therefore, the median error of reading was taken as the measure of central tendency. The first step was to compare the daytime with the nighttime distribution for each dial for goodness of fit. A significant difference was found in the case of only one dial, the 5° 1" dial. Therefore, the other distributions were combined.

Figure 1. shows how the median error of reading is related to both dial size and angular separation. In general, if either is increased the median error of reading is decreased, or, the larger the dial the lower the error of reading. However, this relationship holds much better for the smaller dials than for the larger. In order to see why this is so, Figure 2 shows the separate contribution of each variable. Notice that for dials having 5° of angular separation, 10° of angular separation, and 20° of angular separation between subdivisions an increase in diameter results in a decrease in error of reading. But for dials having 40° of angular separation the lowest error of reading is attained with a diameter of two inches, any further increase in size resulting in decreased accuracy of reading. Furthermore, the shape of the curves suggest that had dials with five and six-inch diameters been used the first three curves would have reached their lowest point and perhaps started ascending as did the 40° curve. The tentative conclusion is that a dial may be both too small or too large for most accurate reading. If dial diameter must be restricted, say, for structural reasons then large angular separation is desirable. But if a dial may be any diameter then care must be taken not to exceed the most efficient angular separation.

Since it is apparent that both diameter and angular separation affect error of reading, the question arises whether or not these factors can be reduced to one common variable which will account for the results. Physically, a change in either diameter or angular separation results in a change of a single common dimension namely, the actual linear distance between subdivision marks. These linear distances can be derived by computing the circumference of each dial and taking that portion of it represented by the angular separation in question. Figure 3 shows the relationship between median error of reading and linear distance between subdivisions. Although the relationship is very marked and again suggests that the distance may become too large for most accurate reading, nevertheless it is doubtful if this common variable can be used as a substitute for the consideration of both diameter and angular separation since linear distance does not account for all the varience in median error of reading. On several occasions two and sometimes three dials had the same linear distance between subdivisions yet differed in diameter and angular separation. One such instance is shown by the marked vertical line across the curve. Here dials 40° 1", 20° 2" and 10° 4" had the same linear distance between subdivisions, and yet there is a significant difference between the median error of reading for the 40° dial and the median error of reading for the 10° 4" dial. Other such

instances of significant differences were found. Unfortunately, data were not complete enough to determine how error varied with diameter and angular separation when linear distance remained constant. It may be that variation under these circumstances is too small to be worth practical consideration, in which case linear distance is the only factor which need be considered.

Results with respect to time of reading were for the most part inconsequential. It was found there was a significant difference between night and day conditions for all dials, the nighttime readings being slower than the daytime readings. With respect to the effect of diameter and angular separation on the time of reading somewhat the same results were found as were found in the case of errors. But the total range in median times was so small (.25 seconds daytime; .48 second nighttime) that time of reading as measured in this experiment was not considered to have selective value in the design of dials.

Miscellaneous results. We were unable to find any evidence in this experiment that some portions of a dial were read more accurately than other portions when all errors were considered positive. When errors were given their proper sign, some significant differences were found, but their direction was not consistent and their meaning was unclear.

It will be remembered that the error distributions showed in some cases a tendency to bimodality at the high end. Since this peak occurred about an error of ten, it was assumed that this represented an error of reading the first digit of a setting involving two digits. Some dials were more susceptible to these errors than were others, but no consistent relation between this type of error and the size and angular separation of the dial could be found. Similarly, instances where subjects appeared uncertain of their response to the extent that they would reverse themselves and give a second response were kept track of. Dials differed in their susceptibility to these reversals, but again size and angular separation characteristics were not related to this tendency.

[redacted]D

ANGULAR SEPARATION

DIAMETER	5°	10°	20°	40°
4"	1.38	.93	.83	.94
3"	1.55	1.06	.93	.81
2"	1.97	1.28	1.14	.80
1"	3.10/ 2.18	1.83	1.41	1.26

Median Error
Fig. 1

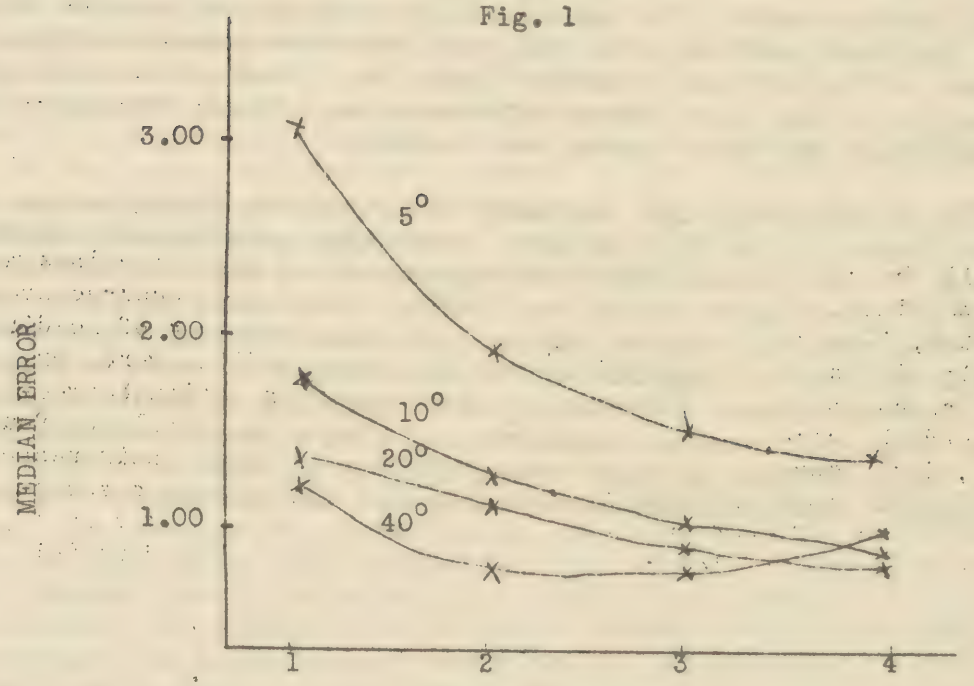

Fig. 2

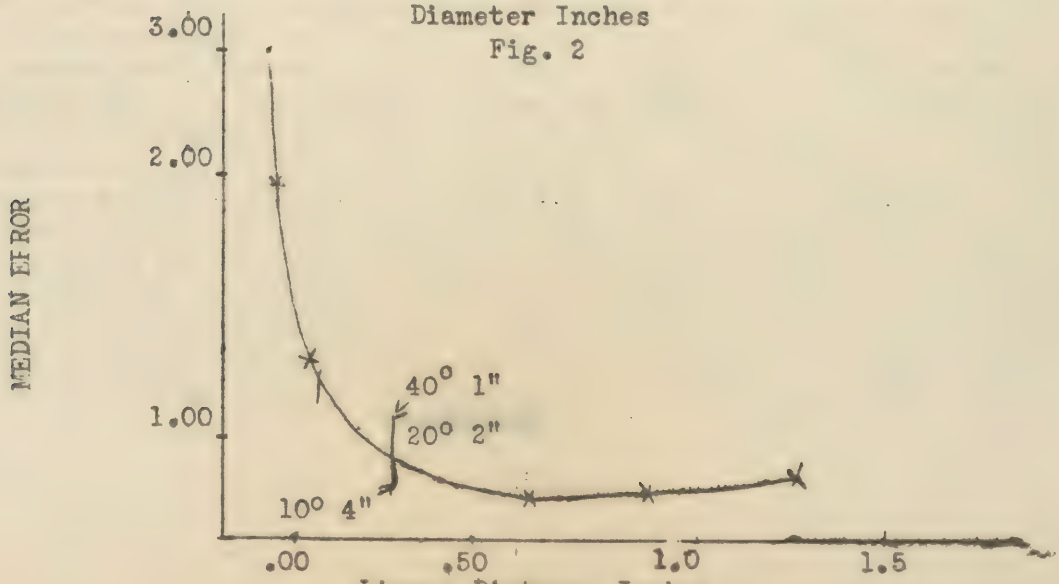

Fig. 3

DESIGN OF CLOCK DIALS FOR GREATEST SPEED AND ACCURACY OF READING IN MILITARY (2400 HOUR) TIME SYSTEM[1]

Walter F. Grether
Aero Medical Laboratory, Wright Field

INTRODUCTION

People commonly experience difficulty in using the 2400 hour time system which has become standard in military practice. When military time is read from a 12-hour dial, it is necessary to add 1200 to all readings after 12:00 a.m. The mental arithmetic thus required introduces an opportunity for error and also some delay in obtaining the desired figure. On the other hand, 24-hour dials designed to give readings directly in military time are, at first glance, quite confusing to persons who have spent their entire life reading time from 12-hour clocks. In the 24-hour dial, only one of the hourly positions can appear in its conventional location. In addition, an interval of one hour on the hour scale corresponds to $2\frac{1}{2}$ instead of 5 minutes on the minute scale. One of the major purposes of this experiment was to find out whether the 12-hour or 24-hour dial can be read more easily when readings are required in military time. A further purpose was to evaluate a number of the possible factors in the design of either type of dial which might influence speed and accuracy with which readings are obtained.[2]

EXPERIMENTAL MATERIALS AND PROCEDURE[3]

With the assistance of personnel in the Instrument and Navigation Branch of the Equipment Laboratory, 11 different designs of clock dials were prepared. A sample of each of these designs is presented in Figure 1. The first 5 clocks, types A through E, are variations of the 12-hour clock. The remaining 6 are variations of the 24-hour clock. The 11 clock dial designs used in the experiment were selected in order to make possible a comparison of the following variables:

1. This chapter is based upon research findings reported in Hq. AMC, Engineering Division, Memorandum Report Number TSEAA-694-8.

2. This problem was suggested by the Instrument and Navigation Branch of the Equipment Laboratory, Engineering Division, Wright Field.

3. Dr. John T. Cowles assisted in the preparation of experimental materials for this study. The necessary photographic work was done by the Aero Medical Laboratory Publications Unit.

1. A 12-hour vs. a 24-hour dial.
2. Use of numerals vs. no numerals on the minute scale.
3. Use of 1-minute vs. 5-minute graduations on the minute scale.
4. Use of numerals at all hourly positions vs. replacement of some numerals with mere reference marks.
5. Addition of a 13- to 24-hour scale to the 12-hour dial vs. no such scale.
6. Placement of the 24-hour position at the top vs. the bottom of a 24-hour dial.
7. Placement of the 60-minute position at the top vs. the bottom of a 24-hour dial.

Mock-ups of the 11 clocks were prepared with movable hands and then photographed with the hands in different positions to make up the actual items of a printed test. This test was made up in two parts. In Part I there were 10 reproductions of each clock face. The different dial designs were intermingled in a predetermined irregular sequence so that the subject was required to change from one dial to another as he worked on the successive items of the test. A time limit was used for the entire part, and thus no speed data could be obtained for any individual dial design. Part II of the test was prepared with 10 reproductions of each dial presented successively, thus making possible the use of a time limit for each of the 11 designs presented. In Part II, therefore, both accuracy and speed data could be obtained.

In selecting the time settings to be used in the actual test, an attempt was made to control the average difficulty of the items for all clocks, by equating such factors as number of am. and p.m. readings, number of readings at 5 minute positions, average magnitude of minute readings, and the number of hour readings at major positions (i.e., 3, 9, 12, 15, etc.) In determining the sequence in which the test items appeared in Part I of the booklet, precautions were taken to insure that there was no grouping of a particular clock near the beginning or end of the test. The actual test items used in Part II of the test used different time settings from those used in Part I

This test was administered to 62 rated military personnel at Wright Field and to 100 advanced mathematics students in a Dayton high school. All subjects took Part I of the test prior to Part II. In taking Part II of the test, however, approximately one-half of the subjects began at the front of the test booklet. The remaining one-half of each group took Part II of the test in reverse order. That is, they first completed the 10 items for the last dial design in the booklet in the order in which they appeared, then those for the second last dial design in the booklet, etc. For the rated military personnel, a time limit of 15 minutes was used on Part I of the test and a time limit of 45 seconds on each section of Part II of the test. For the high school students, a 19-minute time limit was used for Part I and a 1-minute time limit for each section of Part II.

RESULTS

A summary of the major results of this experiment is presented in Table 6.1, which shows the percent errors (of one or more minutes) on each clock, for both parts of the test, and for both groups of subjects. The table also shows the time per clock reading in seconds for Part II of the test, for both groups of subjects. At the bottom of the table are shown the estimated differences required for significance at the 1 percent level. Wherever the differences in the results for any two clocks are equal to or greater than the differences at the bottom of the table, they can be assumed to be genuine differences and not the result of chance factors.

The results presented in Table 6.1 are also presented in the form of bar diagrams in Figures 2, 3, and 4. It will be noted in Table 6.1 and Figures 2, 3 and 4 that the data for high school students and rated personnel present substantially the same overall picture. In general, also, the differences which appeared among the dials in Part I of the test reappear in Part II. Thus, although many of the differences between dials on one part of the test and for one group of subjects are not significant, the fact that the differences are in the same direction in Part II and for the other group of subjects greatly increases the likelihood that the differences are significant.

In general, accuracy of readings was somewhat lower in Part II of the experiment, probably because the timing of individual sections motivated the subjects to work at greater speed.

In Table 6.2, an analysis is presented of the various types of error made on the different clock dials. Most of the errors were 1 minute, 5 minutes, 1 hour, or 12 hours in magnitude. The frequency of each of these types of error is presented for each dial for a random sample of military personnel and another random sample of high school students.

INTERPRETATION OF RESULTS AND CONCLUSIONS

Twelve-hour vs. 24-hour dial.

Comparison of the first 5 with the last 6 clocks in Table A shows that there is no major advantage in favor of either the 12- or 24-hour dial, although 24-hour dials, Types G and J, are superior to the two best 12-hour dials, Types A and B. This is particularly true for speed of reading. The 24-hour clock showed somewhat more 1-hour errors, probably because of the smaller spacing of the hour numerals.

Numerals vs. No Numerals on Minute Scale.

The comparison of clocks A and B does not reveal any significant advantage to placing numerals on the minute scale of a 12-hour dial. In the case of the 24-hour dial, however, as indicated by comparison of clocks F and G, there does appear to be a definite advantage in favor of numerals on the minute scale. Dials without numerals on the minute scale show a somewhat higher proportion of 5-minute errors in Table 6.2

One-minute vs. 5-minute Graduations on the Minute Scale.

Comparison of Clocks A and C, and F and I indicates a significant difference in favor of placing graduations at 1-minute intervals when readings are required to an accuracy of one minute. Clocks C and I show a high proportion of 1-minute errors.

Numerals at All Hourly Positions vs. Replacement of Some Numerals With Mere Reference Marks.

Comparison of clocks A and D, and clocks F and H indicates a loss in accuracy when numbers are omitted at some of the hourly divisions.

Addition of a 13- to 24-hour Scale on a 12-hour Dial.

Clock E, with the 13- to 24-hour scale added, was inferior to clock A without such a scale.

Placement of 24-hour Position at the Top vs. the Bottom of a 24-hour dial.

Clock G, with the 24-hour position at the top, was best in Part I of the test, whereas J, with this position at the bottom, was best in Part II of the test. This would suggest that in a situation where an individual can become accustomed to reading a particular clock, as in Part II of the test, there is some advantage to placing the 24-hour position at the bottom of the dial.

Placement of the 60-minute Position at the Top vs. the Bottom of the 24-hour dial.

The results for clock K show quite clearly that the unconventional location of the 60-minute position at the bottom of the dial causes a high percentage of errors and should therefore be avoided.

SUMMARY AND CONCLUSIONS

The purpose of this investigation was to evaluate a number of the possible factors in the design of clock dials which affect the speed and accuracy of readings in military (2400 hour) time. Five experimental variations of the 12-hour dial and six variations of the 24-hour dial were presented as items in a printed test. This test was designed for obtaining data on both speed and accuracy of readings of the 11 different types of clock dial. This test was administered to 62 rated military personnel and to 100 advanced high school students. From the results of this investigation, the following conclusions are drawn:

1. The best 24-hour dial can be read more quickly and accurately in military time than the best 12-hour dial.
2. Numerals on the minute scale (as contrasted with lack of such numerals) increases clock reading speed and accuracy, particularly for the 24-hour dial.

3. When readings are required to an accuracy of 1 minute, dials with 1-minute intervals on the minute scale can be read more quickly and accurately than dials with 5-minute intervals.

4. The replacement of some of the hourly numerals with mere dots or reference marks reduces the speed and accuracy of clock reading.

5. The addition of a 13- to 24-hour scale to a 12-hour dial for afternoon readings does not increase the ease of reading a 12-hour dial in military time.

6. The placement of the 24-hour position at the bottom of the hour scale appears to be slightly superior to its placement at the top of the hour scale. This dial arrangement leaves the noon (12-hour) position in its conventional location, and gives the hour hand a logical relation to the rotation of the sun about the earth.

7. Placement of the 60-minute position at the bottom of the minute scale on a 24-hour dial (as contrasted with the conventional location at the top) greatly decreases the accuracy of clock reading.

8. The results suggest that the best dial for readings in military time would be a 24-hour dial with the midnight (24-hour) position at the bottom of the hour scale, with the 60-minute position at the top of the minute scale, with 1-minute graduations on the minute scale, with numerals at 5-minute graduations on the minute scale, with numerals at all positions on the hour scale, and with shading of the lower half of the dial to represent nighttime.

TABLE 6.1

PER CENT ERRORS AND TIME PER READING FOR ELEVEN EXPERIMENTAL CLOCK DIALS

	Rated Military Personnel N = 62			High School Students N = 100		
	Part I	Part II		Part I	Part II	
Clock type	Percent errors	Percent errors	Sec. per reading	Percent errors	Percent errors	Sec. per reading
A	7.2	6.4	5.28	12.2	11.8	7.52
B	5.6	7.1	5.39	8.6	13.8	7.88
C	19.0	19.1	5.61	27.4	23.5	8.55
D	8.7	13.3	5.69	13.0	20.9	8.24
E	7.3	14.5	5.34	13.0	23.9	8.10
F	7.4	8.0	4.93	13.3	15.6	6.90
G	4.2	6.8	4.79	6.1	8.4	6.56
H	10.8	17.3	5.40	15.5	22.8	7.95
I	12.8	17.7	5.45	19.6	29.5	7.79
J	7.7	3.6	5.02	14.7	4.9	6.86
K	42.8	14.7	5.64	35.9	14.2	7.82

Significance of Differences

When the average error score for two clocks being compared is	5%	10%	20%
The results can be considered significant (1 percent level of confidence) if the differences between clocks are equal to or greater than the following: For rated personnel	3.5%	4.7%	6.2%
For High School students	3.5%	4.0%	5.4%

The results for time per clock reading can be considered significant (1 percent level of confidence) if the differences between clocks are equal to or greater than the following:

For rated personnel	.20 sec.
For high School students	.31 sec.

[redacted]

TABLE 6.2

FREQUENCY OF SEVERAL TYPES OF ERROR IN READING ELEVEN EXPERIMENTAL CLOCK DIALS (PART II OF TEST)

	Rated Military Personnel N = 20				High School Students N = 20			
	Size of error*				Size of error*			
Clock type	1 min.	5 min.	1 hr.	12 hr.	1 min.	5 min.	1 hr.	12 hr.
A	3	5	3	0	2	7	4	0
B	0	3	1	4	4	1	5	3
C	10	8	8	4	9	11	13	1
D	3	9	8	1	5	7	5	3
E	4	11	8	6	2	11	8	8
F	2	4	5	0	3	7	12	0
G	1	4	7	0	1	4	14	0
H	10	6	6	1	7	6	12	0
I	16	7	9	0	11	6	10	0
J	2	1	1	1	1	0	5	0
K	5	0	2	2	4	0	5	0

* Entries in table are total number of errors of size indicated, regardless of direction, for 20 randomly selected subjects.

[redacted]

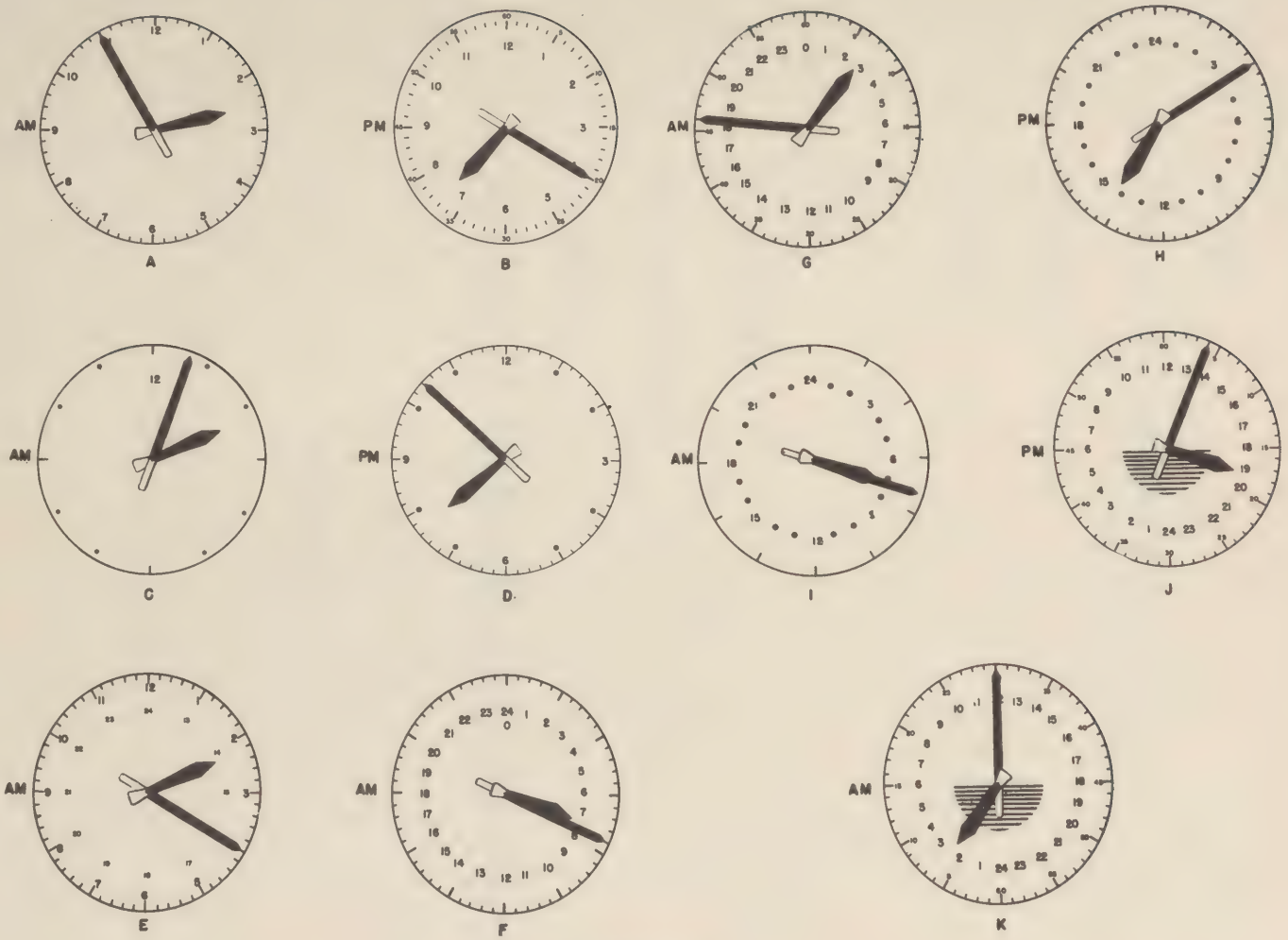

FIGURE I

EXPERIMENTAL DESIGNS USED IN THE STUDY OF CLOCK DIALS FOR READING IN THE MILITARY (2400 HOUR) TIME SYSTEM.

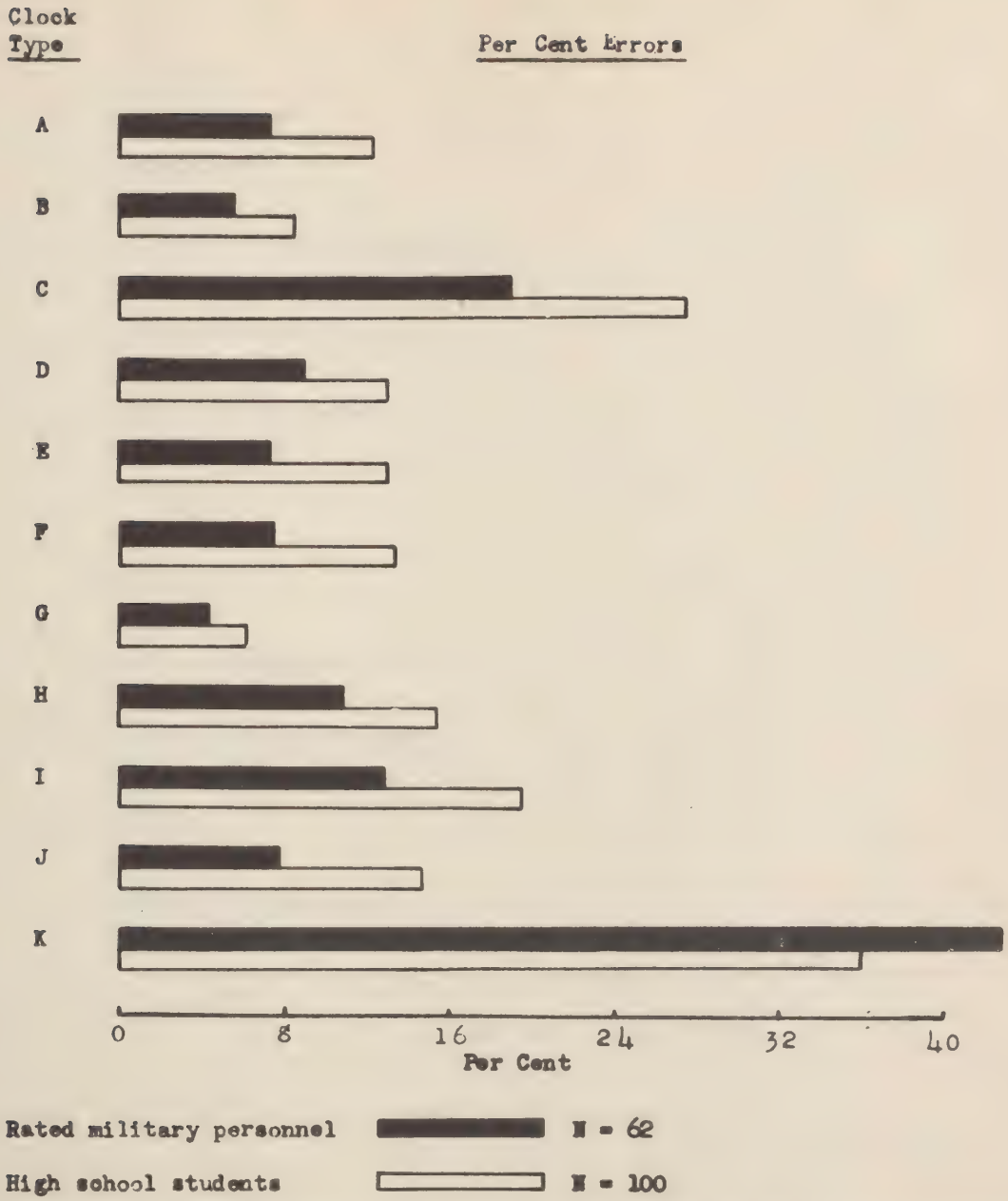

Figure 2. Per cent Errors in Military Time Readings on Eleven Experimental Clock Dials (Part I)

4630 C-A M L

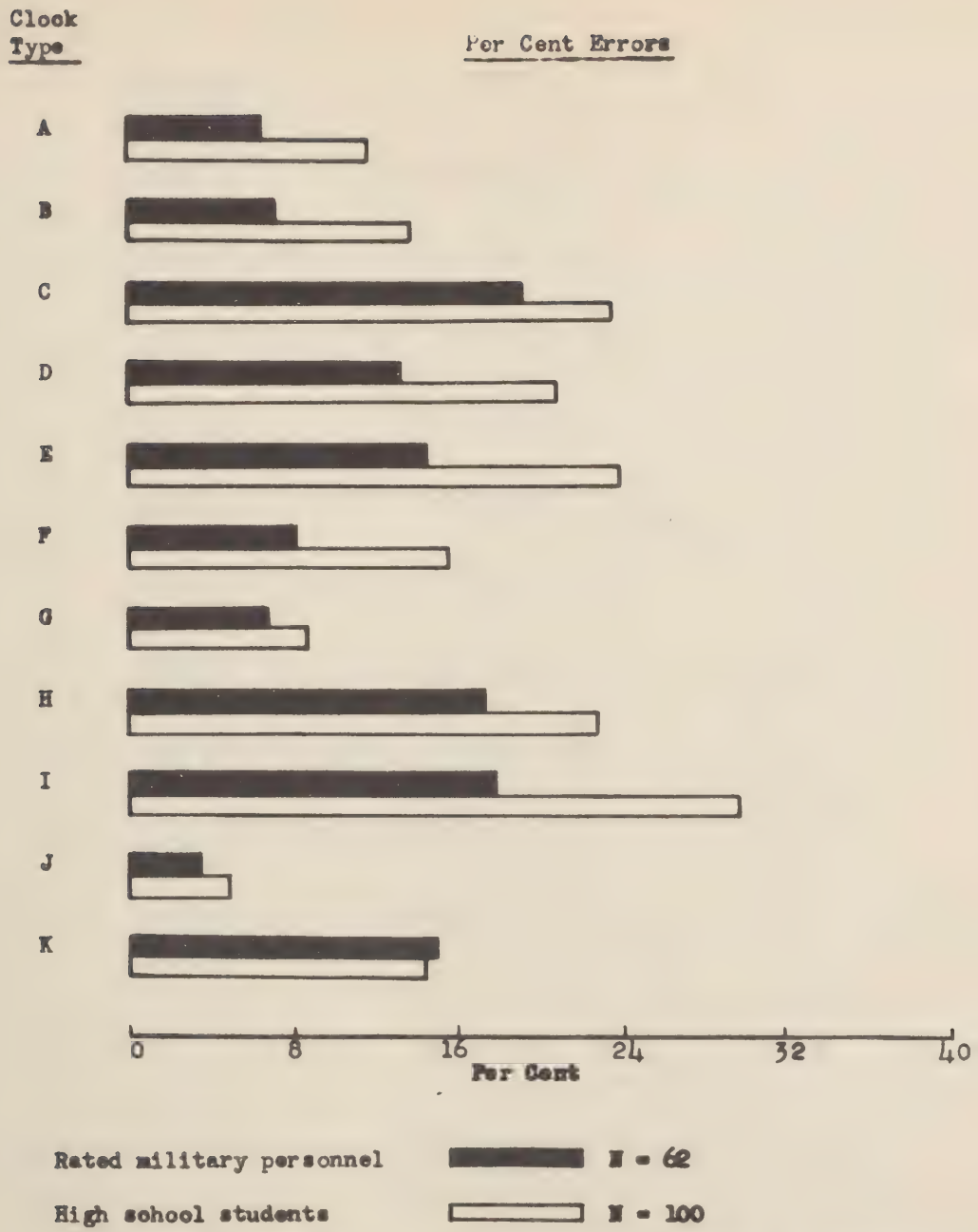

Figure 3. Per Cent Errors in Military Time Readings on Eleven Experimental Clock Dials (Part II)

4630 - B A M L

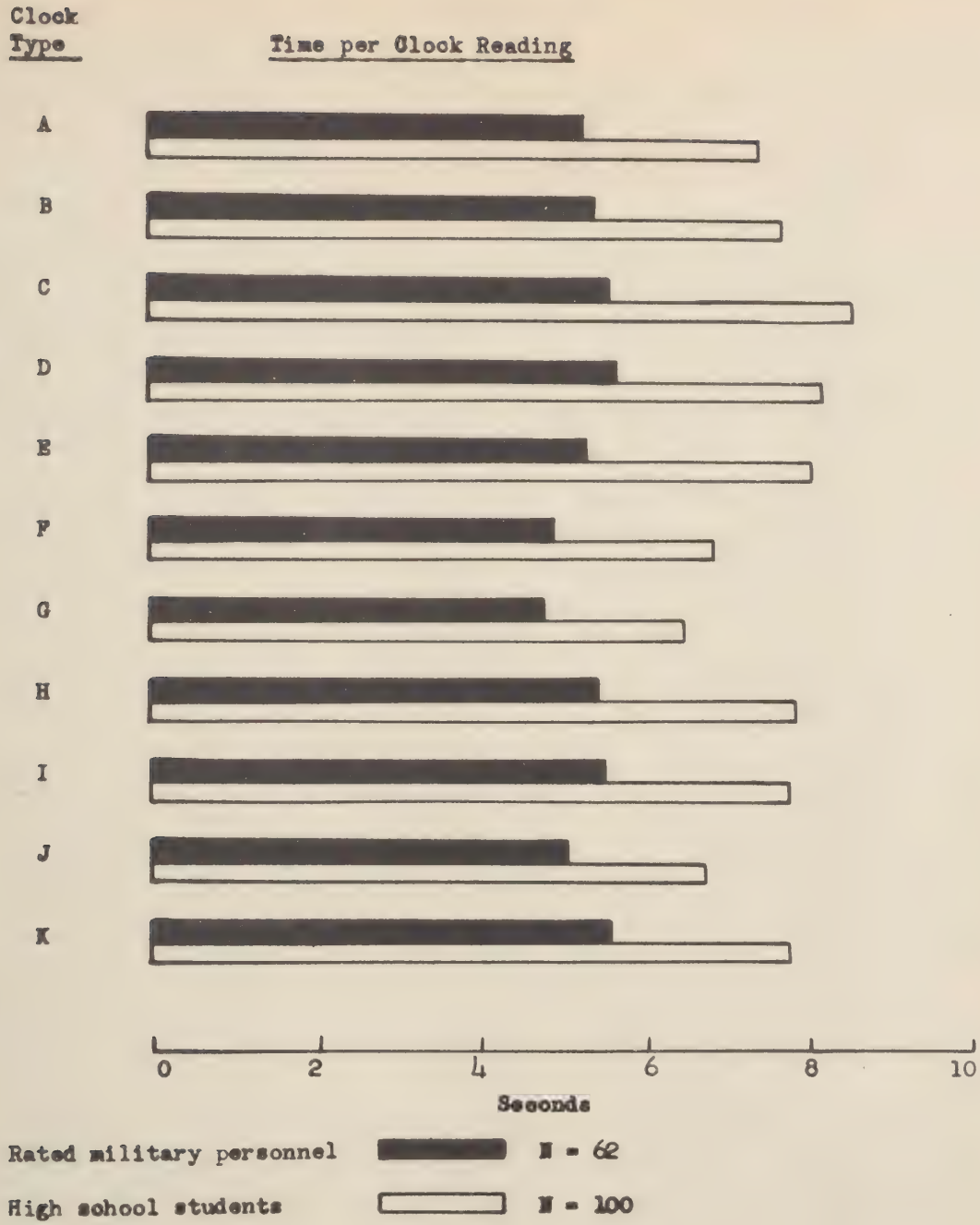

Figure 4. Speed of Military Time Readings on Eleven Experimental Clock Dials (Part II)

4630 A-A M L

[redacted]

DESIGN OF VISUAL INDICATORS TO PROVIDE SPATIAL ORIENTATION

Roger Brown Loucks
University of Washington (Army)

The adaptability of the human organism is such that an individual with normal aptitude can learn to interpret almost any type of flight indicator. There are important differences, however, in the ease and accuracy with which particular types of instruments can be interpreted. Numerous characteristics govern the interpretability of an indicator quite apart from its legibility, which is dependent upon such factors as size and style of numerals or spacing of division marks.

As early as 1930, it was noted that certain types of artificial horizon indicators were somewhat unsatisfactory because the attitude of the aircraft had to be inferred from the relative position of several moving elements and could not be grasped directly. Thus the reports of the early experiments in blind flying, financed by the Guggenheim Fund and conducted by Lt. James N. Doolittle through the courtesy of the Army Air Corps, state that one objective of this work was "the procurement of a flight indicator which would be simple and more direct in its indication and require less translation and mental effort on the part of the pilot," (1, p. 14). There can be no question but that simplicity of design and directness of interpretation play an important role in the relative intelligibility of an instrument. And in the case of certain indicators, there are such striking differences of design that a group of experts can evaluate the relative interpretability of the two instruments on the basis of casual inspection. It has been demonstrated in previous experimental work, however, that the type of design preferred by an individual does not necessarily result in the best performance when he actually uses that instrument.(2) In other words, it is highly desirable that the final evaluation of a particular instrument design be established on the basis of objective measurements of performance rather than subjective opinion.

In attempting to assess the relative effectiveness of a particular aircraft instrument design, the performance of novices should be weighted very heavily. In the experienced pilot, the veneer of training has so thickly covered the original direct, and "natural" responses to certain conventional indicators that it is almost impossible to recall the difficulties he experienced when beginning instrument training. Rated pilots can often give useful suggestions as to particular situations or maneuvers which should be taken into account when evaluating a particular type of instrument. But experienced airmen frequently hold widely differing views as to the effectiveness of a particular instrument design or panel arrangement. It is evident that each pilot's opinion arises out of his particular training and experience. Inasmuch as the subjective impressions of consultants tend to be so very diverse, the only sound basis for a comparative evaluation of two instrument designs is the objective performance of representative individuals whose training and experience are known.

[redacted]

The basic effectiveness of instrument designs can be determined by measuring the rapidity with which equated groups of novices master the use of the respective indicators. Considered merely from the standpoint of efficiency in pilot training, the instrument which can be correctly read with the minimum of training has an important and practical advantage over other designs. It is also significant that any skill which is acquired with relatively little effort must, for that very reason, be compatible with the subject's habitual and inborn reaction tendencies. The indicator which the novice can interpret most easily provides the minimal possibility of error when used by an experienced pilot who has been trained on that same instrument. In contrast, the indicator which is difficult to master usually causes confusion because it tends to elicit perceptual-motor responses which conflict with those required for correct interpretation. The ambiguous instrument requires the subject to inhibit or block his immediate or direct response tendency, and forces him to substitute an "unnatural" or sophisticated reaction. Inasmuch as an individual's perceptual habits are generally built up over a period of years and, in many instances, are based upon inborn reaction tendencies, an instrument which requires a subject to break up well-established response systems is to be avoided wherever possible. A needlessly long period of training is required to master such types of instruments, and the possibility can never be completely eliminated that under conditions of stress or fatigue the pilot may revert to his original and more "natural" way of interpreting the instrument. Under the emotional stress and distraction of an emergency situation, there is always a certain probability that a pilot will misinterpret an indicator if he has had to disrupt or block his "natural" response in learning to use the instrument. Any indicator which is ambiguous to the novice is a potential source of error to even the experienced pilot, particularly in those situations which produce excessive stress or fatigue. The instrument which the novice has difficulty in interpreting is thus not only inefficient from the standpoint of training, but a potential source of aircraft accidents. The data obtained from the performance of novices are, therefore, of unique importance.

Although the fundamental data with regard to the interpretability of particular instruments must be obtained from novices, there are certain practical considerations which enter into the overall evaluation of a specific design. Whenever a new instrument is introduced, there are large numbers of pilots, trained on conventional instruments, who must master the use of the new design. It is essential, therefore, that experienced instrument flyers be tested in order to determine the relative degree of confusion caused by a new design. Where there is the possibility of a choice between two new designs, each of which is superior to the conventional instrument as judged by the performance of novices, the one which causes the experienced pilot the lesser degree of habit interference is obviously the better of the two. In certain instances, an innovation can be introduced without causing the experienced pilot any difficulty because the change is so radical he reacts to the modified design as if it were a unique instrument. He shows no tendency to reinstate the habits established during previous instrument training.

To insure a thorough and comprehensive evaluation of an instrument requires that it be tested in a variety of situations. A particular type of indicator might be easily interpreted so long as the pilot is flying solely by instruments and using the interior of his cockpit as a fixed point of reference. When the pilot is flying partly by instruments and partly "contact", the true horizon may function as the fixed point of reference. It is conceivable that an instrument which proves satisfactory in the first situation may lead to confusion in the second. Some pilots when flying blind see the cockpit as stationary. As a consequence, the horizon bar and pointer of the conventional attitude indicator, to take but an example, appear to move with regard to fixed points of reference on the instrument panel. In the second situation, where the pilot is flying contact part of the time and using instruments part of the time, it is possible for him to perceive the true horizon as remaining fixed, and the instrument panel as rotating about the "fixed" horizon bar and pointer of the attitude indicator. A particular instrument should, therefore, be tested in each of the above situations. Furthermore, since visual perceptions of relative motion are influenced to a certain degree by accelerations, which affect the semicircular canals and kinesthetic sense organs, data obtained with static or moving ground-trainers should be checked by measurements taken during actual flight. Various pilots have reported a feeling of vertigo when using a particular attitude gyro in cloud formations, and it is obvious that ground-trainer work with such types of instruments should be supplemented by tests in the air.

While the effectiveness of a particular instrument design should ultimately be verified under actual flight conditions, the cost of personnel and equipment would be prohibitive were an instrument study to be conducted exclusively in planes. Due to the inevitable differences in instrument flying aptitude, it may require a minimum of 60 subjects to determine whether there is a reliable and significant difference between the relative effectiveness of two specific designs. Once the superiority of a particular instrument design has been established, it may require a long series of comparative measurements to isolate the basic elements in the design which cause the difference. In consequence, it may be necessary to test several hundred subjects in order to make an analysis that is reasonably thorough. The mere factor of the time required to process several hundred subjects in test flights makes it impractical to conduct such a project exclusively in the air. It should be noted, moreover, that under actual flight conditions there are so many variables which influence pilot performance that it would be very difficult to determine the proportion of the total achievement which could be attributed to the use of a particular instrument. Fluctuations in air conditions tend to introduce so much variability in performance that the effect of any one factor, such as the use of a particular instrument, may be largely masked. Finally, the problem of objectively quantifying performance during actual flight is, in itself, an extremely difficult task.

In view of the considerations just presented, it is necessary to conduct the greater part of an instrument evaluation study by making comparisons of various indicators in the ground-trainer situation. This makes it possible to exclude many of the factors which tend to make the true flight situation so variable. The experimenter thus gains much more adequate control of the test situation and can standardize the factors which influence performance. This approach does not obviate the need to verify various instrument comparisons during actual flight. There are numerous air maneuvers which cannot be simulated by the ground-trainer.

The work now being initiated at the University of Washington, under contract with the Psychology Branch of the Air Materiel Command's Aero Medical Laboratory, has to do with the general problem of orientation. One of the projects being undertaken within the general program is the determination of the relative interpretability of various types of direction indicators. Because this involves maneuvers which are limited to turning in azimuth, a simplified ground-trainer has been constructed for use in this work. The construction of a new ground-trainer was undertaken, in part, because of the extensive and highly specialized maintenance required by the Link ground-trainer, and the very serious problem of keeping such a device in calibration. Stability of instrument-trainer performance is essential in such work so that performance scores obtained on successive subjects and under varying experimental conditions can be treated comparably.

The new and simplified ground-trainer is supported on a B-29 turret mounting ring, and uses the associated motor and autosyn assembly for turning the unit and indicating position, respectively. The original direct current turret motor has been reconnected so that it runs as an induction motor and has a high degree of speed-constancy. The trainer fuselage contains a conventional bucket seat, simulated control stick, rudder pedals, and instrument panel. The control stick can be moved, but turning of the trainer is actually initiated by adjustment of the rudder pedals. The instrument panel contains only two instruments, and only one of these is exposed at a time. Each of the panel instruments comprises an autosyn indicator mechanism electrically coupled to the transmitter autosyn at the turret-ring driving unit. The autosyn position indicators readily lend themselves to transposition of dials, pointers, and substitution of counterclockwise rotation for clockwise movement. A series of headings is presented to the subject on a ground glass window, just below the instruments. The subject's task is to manipulate the rudder pedals so that the trainer turns to the heading presented on the ground glass and the setting of the exposed indicator conforms to the assigned heading. In going from one heading to another, the trainer turns at the conventional rate of one revolution in two minutes. Upon arriving at the correct heading, the subject must stop the trainer. After a delay of 2.5 seconds, a stepping switch automatically presents a new heading on the ground glass window. The test is terminated after the subject has completed a specified number of compass headings, the task being self-pacing. Performance is scored in terms of the number of reversals the subject makes in going from an established heading to an assigned heading, the direction of his path, the number of times he starts and stops and the length of time he takes to react to each new setting that appears on the ground glass window. All of these measures are automatically recorded on electromagnetic counters and timers.

Comparisons will eventually be made between a variety of direction indicator designs of which certain instruments will contain dials which rotate in relation to a fixed index. Other designs will consist of horizontally rotating compass cards as contrasted with the remote indicating type of dial instrument. By throwing a switch, the clockwise movement conventionally associated with clockwise azimuth rotation of aircraft can be converted to counterclockwise rotation. This will make it possible to determine the most favorable type of relationship between direction of pedal displacement and dial rotation. It will also be possible to determine whether any specific relationship is particularly superior as regards direction of foot movement in relation to the displacement of reference points outside the trainer.

When it has been determined which types of indicator are most easily interpreted under blind flying conditions, further checks will be made with the canopy up so that the action of the instrument can be evaluated with regard to external reference points of reference. Finally, experienced instrument flyers will be tested with various critical instruments to get an estimate as to the amount of interference that is produced in subjects who have been trained on other styles of indicators.

An analogous experimental evaluation of aircraft attitude indicators was conducted by the speaker while at the AAF School of Aviation Medicine, Randolph Field, Texas, using the objectively scored performance in a Link ground-trainer as the basis of comparative evaluation(2). Tests made with aviation cadets demonstrated important differences in the relative intelligibility of various types of artificial horizon indicators. The present work being conducted at the University of Washington, under contract with the Air Materiel Command, is only now getting under way but preliminary results based on a relatively small group of subjects suggest that the objectively scored performance in the simplified azimuth trainer will also uncover highly significant differences in the relative interpretability of various types of direction indicators.

The azimuth trainer will also be used in collecting certain data desired by the Air Materiel Command with regard to problems of map orientation and, possibly, certain features of radar navigation and bombing involving orientation. Many airmen feel that a map is most easily used when its North points to geographic North. Others believe that the map's North should always be aligned with the nose of the plane irrespective of true North, because instruments such as the fluxgate compass and azimuth stabilized radar scopes have North at the top of the indicator. A number of the fundamental features involved in the use of maps under blind flying conditions can be simulated by having the subject orient the trainer in alignment with a sequence of letter headings, presented on the ground glass window of his instrument panel, which correspond to a series of equally distant points on a reference map. Starting from an assumed position on the map, the subject is required to maintain his heading for a period corresponding to the time required to fly from one point on the map to another. The stepping switch then automatically presents a new heading. When the variables involved in interpreting maps, or, possibly, radar screens under conditions of blind flying have been investigated, checks will be made of the influence of moving reference points external to the trainer. Wide canvas belts painted to simulate terrain as seen from an elevation, will be observed by subjects through windows in the trainer. The direction and relative rate of motion in these moving bests will be shifted as the heading of the trainer is altered . This will make it possible to simulate the situation, for example, in which the apparent movement of the ground is from forward to aft, whereas the track of the aircraft on the reference map may represent a heading of 270 degrees. Analogous experiments involving the use of this trainer are also planned for the evaluation of radar screens where the radar-navigator-bombardier must shift from azimuth stabilization to a non-stabilized type of presentation.

In all the projects discussed above, the major goal is the gathering of objective measures of performance rather than evaluations based merely on subjective opinion. Because, as it was pointed out above, the performance data obtained with novices are of such unique importance, the greater part of this program will be conducted on this class of subjects. Whereas a large part of the work will be done under simulated blind flying conditions, checks will be made in situations which simulate many of the essential characteristics of contact flying. It is recognized that this program must ultimately be supplemented by measurements of performance during actual flight. Nevertheless, it is believed that most of the factors which will insure optimum interpretability, can be worked out with ground-trainers along the experimental lines described above.

BIBLIOGRAPHY

1. Daniel Guggenheim Fund for the Promotion of Aeronautics, Inc. Solving the problem of fog flying: A record of the activities of the Fund's Full Flight Laboratory to date. October 9, 1929. pp 52 plus ii.

2. Loucks, Roger B. Evaluation of aircraft attitude indicators on the basis of Link instrument ground trainer performance. Project 341. 27th AAF Base Unit, AAF School of Aviation Medicine, Randolph Field, Texas, 22 June 1945.

DISCUSSION: Wednesday Morning

Lt. Commander Farnsworth commented on the "staircase" scale devised by Mr. Christensen. He pointed out that it was logical for a small length of line to represent a small number, but that looked at from a configurational standpoint, the staircase should be reversed so that a descending staircase would appear as an arrowhead indicating the direction in which the eye should move.

Dr. Ellson asked Dr. Loucks whether the subjects in his experiment were able to estimate their location from the noise of the motor turning the turret.

Dr. Loucks agreed that there were some auditory cues of motor noise present.

Mr. Goldberg emphasized the twin nature of the task of reading instrument dials. Often it is necessary for the operator to read the exact number indicated by the dial, but more and more at high speed operation the operator's chief task becomes that of knowing the general position of the dial without stopping to read the exact value. For this reason, in many instances the use of counters is not feasible and instead, dials of another sort are necessary.

Mr. Goldberg also emphasized the necessity for standardizing on numerals which cannot be misread when they are viewed upsidedown.

Commander Dyke, in connection with the papers of Dr. Kennedy and Dr. Dudek, suggested that the effects of vibration of instrument panels might well be investigated in a preliminary way by producing optical blurring of numerals. He suggested a simple shadow projector which would make such blurred presentations an easy matter.

In answer to Commander Dyke's question as to whether such a device had been tried, Mr. Gleason reported that to his knowledge it had not been.

Mr. Blackwell questioned the validity of the technique suggested by Commander Dyke for investigating the effect of motion upon legibility. He pointed out that the effect of a moving stimulus pattern on the retina would undoubtedly not be the same as that of a fixed, blurred image. For example, it might well be found that a moving numeral would be more visible than a steady numeral, whereas there is no reason to expect that a blurred numeral would be more visible than a distinct numeral.

Commander Dyke asked about the means of selecting the numeral design used in military instruments. He wondered if designers who have had great experience with such matters had been consulted in this matter.

Mr. Goldberg reported that the Bureau of Ordnance standardized on numeral design on the basis of service recommendation. It was agreed that the selection of numerals had been done with but little scientific investigation.

Mr. Sleight reported that Mr. Gleason and he had investigated the literature to ascertain whether careful experiments had been conducted to determine the optimum numeral design. On the basis of replies from dial manufacturers, they concluded that agreement had been reached on the basis of conference rather than by experimental techniques.

Dr. Baer commented that the New York Department of Visual Education had conducted some work in this field and should be contacted.

A question was raised as to whether it was advisable to use photographs of dial scales in conducting experimental investigation of their legibility. In general, this policy has been followed for reasons of convenience. It seemed the consensus of opinion that it would be advisable to construct dials rather than rely upon photographs.

Captain Korb called attention to a booklet recently prepared by the Bureau of Medicine and Surgery entitled, "Annotated Bibliography on Human Factors in Engineering Design". He reported that two or three hundred copies were available which could be obtained upon request through the usual channels. He mentioned also that the Bureau of Medicine and Surgery was anxious to have the Bibliography made current and would welcome proposals from any competent groups to this end.

Captain Korb commented on the gratifying progress made in the past several years in subjecting problems such as those discussed in the meeting to experimental investigation. He felt that the next few years should produce very real results in these fields.

VISUAL PROBLEMS IN INSTRUMENT DESIGN FROM THE ENGINEERS' POINT OF VIEW

Mr. J.P. Callahan
Lt. Col. C.E. Reichert
Aero Medical Laboratory, Wright Field

Mr. Callahan demonstrated a sample aircraft instrument panel and discussed various features considered in its construction. He commented that for emergencies, it was necessary for the dials to be spread out over a fairly large area. For example, he reported that an instrument which combined approximately ten indications was once constructed by Sperry. It was found that in emergencies, the pilot was unable to use this instrument because of the excessive concentration of information.

In reference to the use of flashing lights for warning the pilots about emergency conditions in flight, Mr. Callahan reported that the use of such lights was objectionable to the pilots. In the first C-46, for example, although some 30 such lights were provided, the pilots always carefully covered them with adhesive tape. In reference to the selection of numeral styles, Mr. Callahan reported that the Army and Navy selected their dial designs on the basis of years of experience by gas, electric, and water-meter readers. Mr. Callahan emphasized the necessity for instrument indicators which do not fluctuate, but which have sufficient inertia to hold a steady reading. The general principle being utilized by the AAF instrument designers is to condense the indicators for each engine into one place so that the status of each engine can be observed at a glance. In general, dials have been designed so that under normal conditions the pointers are parallel to each other. In this way, any abnormality forces itself upon the pilot's attention.

Mr. Callahan emphasized the difficulty of providing a P-80 pilot with sufficient instruments to permit him to fly successfully. The P-80 pilot, traveling 10 miles per minute soon loses himself with respect to his navigation maps. In general, research is being conducted along three lines: (1) the development of an instrument which will compute high-speed flight positions, and, by means of a push button, make them available to the pilot; (2) the development of a recording mechanism which will enable the pilot to refer to dial values at any time; (3) the development of a means to free the pilot from the use of maps by automatically giving distances from his base, and bearing. Mr. Callahan remarked that the present system of fluorescent markings, illuminated by ultra-violet, has many engineering advantages over red flood lighting. Lt. Colonel Reichert emphasized the problem of providing the pilot with adequate vision over large areas in modern planes, which of necessity must be free from large flat surfaces. He reported that periscopes had been tried, but that they led to confusion on the part of the pilot and did not provide him with sufficient field of view. Colonel Reichert expressed the wish that an optical device be developed to enable the pilot to have adequate vision in high speed aircraft. In addition to these problems, Colonel Reichert was particularly concerned with the adequate arrangement of instruments in the cockpit.

His group attempted to place instruments on a hemispheric surface so that each instrument would be at an equal fixation distance from the pilot's eyes. Colonel Reichert emphasized that the trend toward larger aircraft and higher speed carried with it a decreased number of personnel whose tasks become increasingly complex.

DISCUSSION:

Various members of the Committee discussed the controversial issue as to whether ultraviolet or red instrument lighting should be used. It was emphasized again that if dark adaptation is necessary to the pilot, red lighting or a red or orange fluorescent material would be more desirable than the present yellow fluorescent material.

Dr. Scobee remarked about the fluorescence of the human lens due to ultraviolet light which produces the impression that the pilot is flying in a fog. He emphasized that although there is no evidence that damage to the eye results from the ultraviolet light, the fluorescence of the lens does reduce the dark adaptation of the pilot.

Various members discussed possible ways to eliminate bothersome front surface reflectance from instrument dials in aircraft cockpits. Suggestions included low-reflection coatings, the use of "pigeonholes" to obstruct the reflections, and the use of Polaroid to reduce specular reflection from the dial faces.

SUMMARIZING REMARKS

D. G. Marquis

Our survey of current and contemplated research studies calls attention to the fact that there are two broad classes of visual problems: (1) direct vision, in which the observer is able to regard the target object directly; (2) indirect vision, in which data are transformed into some type of instrument indication for reading by the observer. Dr. Peskin reminded us that the eye is not a different instrument in these two cases. Its "private life" is the same. The variables which affect accuracy and reliability in the two visual tasks, however, are differant in many respects.

Dr. Fitts pointed out that analyses of the type of mistakes which occur in reading indicators and scales have defined the areas in which further work is needed. Dr. Mead emphasized the need for basic general information so that adequate help can be given to engineers in designing instruments as well as in testing them.

Throughout all the papers three basic variables have been recognized; (1) the design of the instrument presentation itself; (2) the level of illumination provided by the instrument; and (3) problems of the observer, and observer-instrument relations.

It has become apparent that a scientific attack on these problems is extremely fruitful. From the research studies in which specific results have been obtained, it is evident that a 10% improvement can be made rather easily. In many cases, a simple change can result in 100% decrease in errors.

Three general characteristics of the various research programs described in this meeting are striking. The first is the careful planning of a broad and coordinated attack on the various problems of instrument legibility, and it is gratifying to see the Army, Navy, and civilian groups discussing their plans and preliminary results at such an early stage of their research.

The second is the sound factual approach to the problems. The researches have started with an analysis of the job the instrument must perform, and of the errors that occur in that performance. It is interesting to note also that methodology has received specific attention in the planning of the research programs. The experiments have been designed so that results will be clearly interpretable and can be related to the results of other studies.

The third characteristic is the exciting possibility of invention in this field. Original new ideas can be tested in the laboratory and developed for field use. Two years from now we may well expect to hear of many inventions--new instruments--which will come from these studies.

In a comprehensive research program such as we have heard presented here, it is desirable that each experiment strive for maximum generality of its conclusions. A large number of variables have been discussed which affect dial legibility, and in no one experiment can all of these be studied simultaneously. When sufficient data have been collected to warrant a fairly adequate decision, standardization of each of these variables should be made so that data from one laboratory can become immediately comparable with data from other laboratories.

ABSTRACTS

172. Optionic Instruments for the Study of Camouflage.
The Research Laboratories of Interchemical Corporation
Section 16.3, OSRD Report No. 6556, August 25, 1945, 72 pp, (O)

"A number of special optico-electronic instruments used in camouflage research were constructed. The instruments included: (1) a combination reflectometer and microdensitometer, (2) an automatic recording photoelectric goniophotometer, (3) a haze meter, (4) a sun-ratio meter, (5) an alternating current telephotometer, (6) a sun photometer, (7) a horizon scanning photometer, and (8) a sky brightness comparator."

173. Camouflage Finishes and Related Problems.
The Research Laboratories of Interchemical Corporation
Section 16.3, OSRD Report No. 6557, Sept. 24, 1945, 306 pp, (O)

"A report is given of the pigment evaluation summary made to analyze various commercial pigments with respect to their similarity to chlorophyll-bearing vegetation. A new type black pigment is described, which reflected only 2.2% of the incident light instead of the 4 or 5 per cent characteristic of standard matte black paint. This product has been found to be useful for simulating shadows on the ground. A glassy black enamel was developed whose diffuse reflectance was less than 0.1%. It has been found by tests that this paint permits a high degree of success in rendering a plane invisible in searchlight beams and in making it difficult for search light operators to maintain contact with the plane. (This paint was adopted by the RAF and by major units of the AAF for use in every theatre of operations.)

"In addition, work is reported on: (1) Matte Colors, (2) Concentrated emulsifiable paints, (3) high reflectance white, (4) Temperature sensitive paints, (5) adhesive for camouflage, (6) matches for foliage."

174. Visual Factors in the Design of Military Aircraft.
E.A. Pinson and A. Chapanis
A.A.F. - ATSC. Engineering Division, Aero Medical Laboratory, Wright Field
The Journal of Aviation Medicine, Volume 17, Number 2, April, 1946, 8 pp.(O)

"The experience of this war has shown that standards of visibility from military aircraft must be very high for maximum operational efficiency. A number of studies have been undertaken by the Army Air Forces to provide a set of recommendations to aircraft designers regarding the ways in which these standards of high visibility may be maintained. Two groups of studies on the fields of view from fighter aircraft and the optical quality of transparent panels are summarized in this paper."

175. A Device for Demonstrating the Effects of Anoxia on Vision.
A Chapanis
A.A.F. - ATSC. Engineering Division, Aero Medical Laboratory, Wright Field
The Journal of Aviation Medicine, Volume 17, Number 4, August 1946, 9pp. (O)

"The Luckiesh-Moss--Army Air Forces Anoxia Demonstration Charts were devised for demonstrating the effects of anoxia on contrast sensitivity. Results on over 1,000 subjects show that a demonstration with these charts convinces over 90 per cent of indoctrinees at simulated altitudes of 15,000 and 16,000 feet. The demonstration is easy to explain and administer, requires little in the way of apparatus and props, and can easily be completed in fifteen minutes. A survey of AAF Altitude Training Units shows that the demonstration can be successfully integrated into routine high altitude indoctrination flights."

176. A Projection Timer for Visual Research.
C.E. Woollen and F. Hamburger, Jr.
U.S. Navy - ONR. Special Devices Center, Electrical Engineering Laboratory of The Johns Hopkins University
Memorandum report, 166-I-4, 10 November 1946, 11 pp. (O)

"A device is described for providing visual images for research dealing with visual display methods. The apparatus will produce images variable in diameter from three inches to five feet, with exposure times adjustable from 0.15 to 0.8 seconds with build-up and decay time not exceeding four milliseconds."

177. Accuracy of Oral Transmission of Target Information.
A. Chapanis
U.S. Navy - ONR. Special Devices Center, Systems Research Field Laboratory of The Johns Hopkins University
Memorandum report, 166-I-5, 1 December 1946, 12 pp. (R)

"This experiment measured the speed and accuracy with which target (bearing and range) information can be transmitted orally over sound-powered telephones. Teams of two men each were employed in a total of 84 experiments in which target bearings and ranges were read at rates of 4 to 16 per minute, and for various durations ranging from 10 to 60 minutes. Tape recordings were made to discover whether errors had been made by the talker or recorder. The data show that:

Talker vs. Recorder Errors — Most of the errors in the oral transmission of target information are made by the recorder who must receive the information, remember it momentarily, and write the information down. Very few errors are made by the talker, and in general they do not exceed 2% of the total, even at the highest reading rates.

Errors vs. Number of Targets — There is a constant low level of average error (less than 2%) in target information transmitted orally when the rate of reading is 10 targets or less per minute. Errors in target information at reading rates of 12, 14, and 16 targets per minute increase markedly, and at 16 targets per minute reach an average value of 25.5%. This means that a rate of 16 targets per minute, more than one in every four targets relayed by telephone and then recorded contains an error.

Digit-Target Error Ratio vs. Number of Targets — The ratio of number of incorrect digits to number of target errors can serve as a measure of the severity of target-error. This ratio increases as the reading rate is increased. Taken in conjunction with the findings recorded above, this fact means that, at high transmission rates, the percentage of incorrect targets increases and in addition, the errors are more serious because more digits per incorrect targets are missed.

Errors vs. Successive Work Periods — When the data are analyzed in successive 10-minute work samples, there is a consistent increase in the percentage of incorrect targets for successive 10-minute intervals. In every case, there is an increase in the percentage of errors, even between the first and second 10-minute intervals.

Differences Between Subjects — Extremely large individual differences were found among talker-recorder teams in the efficiency and accuracy with which they could transmit target information orally. These individual differences are so large that one profitable attack on the problem of increasing the accuracy of transmitted verbal information would be to select teams of men who are most capable of performing this kind of work. Since personnel selection does not fall within the scope of the research activities of this project, this line of investigation will not be pursued further here. The finding, however, is recorded for the guidance of other research groups which may be interested in this problem.

"Taken as a whole, these experiments demonstrate that there is a very definite limit in average human capacity to perform the kind of work involved in the oral transmission of target information, especially when the rate of transmission exceeds 10 targets per minute."

178. Compilation of Research on Abridgement and Administration of the A.O. 1st Edition Pseudo-Isochromatic Plates.
Dean Farnsworth and Priscilla F. Kimble
Medical Research Department, U.S. Submarine Base, New London, Conn.
Color Vision Report No. 14, X-749 (Av-384-k), 9 December 1946, 21 pp. (O)

"Because of the general need for a more reliable screening test for color vision within the Navy as well as in civilian activities, much investigation has been undertaken on the diagnositc value of the American Optical Co. Pseudo-Isochromatic Plates. About sixteen such researches are utilized in preparing this report.

"A selection of the best plates was made for an abridged edition. The following plates were found to be of highest diagnostic value by four methods of analysis and by a majority of authorities: (Plate No.) 19, 27, 20, 29, 23, 42, 6, 12, 8, 41.

"If less than 2 errors are made on the above series, the examinee is almost certai ly color normal; if more than 5 errors are made, the examinee is almost certainly color defective. If 2 to 5 errors are made, administration of the following less diagnositc plates may increase the reliability of the test: (Plate No.) 43, 14, 24, 9, 40, 21, 10, 44, 35, 36. On the total series of 20 plates, normals are likely to make no more than 4 errors, color defectives not less than 5 errors."

"Demonstration plate No. 25 should precede the number plates and No. 46 should precede the tracing plates.

"The above 22 plates will constitute a serviceable screening test to separate color defectives from color normals in 95% to 99% of the cases tested. Such a test cannot indicate the degree or kind of color defect.

"Each plate should be mounted one to the page so that they can be shown separately and in random order. Until such an edition is issued, the present edition can be utilized by covering the rejected plates with black paper.

"The tests are designed to be given under light of average daylight quality and neither reliability nor validity can be expected under other illuminants. An easel lamp (Macbeth ADE-10) has been designed to hold the plates at correct angle under proper brightness and quality of illumination.

"Proposed instructions for selection of plates, for administration of the abridgment, and for scoring are given in Appendices."

179. Confusions of Colored Lights at Small Subtense by Protans and Deutans
Dean Farnsworth
Medical Research Department, U.S. Submarine Base, New London, Conn.
Color Vision Report No. 13, BuMed X-263 (Av-151-c), 25 September 1946, 20 pp.(C)

"A laboratory survey was made of the recognition of colored signal lights by partially color-defective personnel. In addition to standard signal glasses, certain special filters were studies for their diagnostic value in tests for color-blindness: a yellowish-to-bluishgreen series, pure red, and metameric pairs of orangish-red and purplish-blue.

"It was found that colors which differed in blueness or yellowness were best distinguished from each other by color blinds. Approximately 9% of the males of the United States are known to be color defective and a considerable percentage of partial defectives are included in Naval personnel; therefore, recognition of color signals would be promoted by the use of green signals which are as bluish as is consistent with the condition in which they are used.

"It was found that colors in the region extending from orangish-red and purplish-red at one end of the color diagram to yellowish-green and bluish-green at the other were least distinguishable by color defectives. Therefore, the lantern tests for color vision which utilize yellowish-greens and slightly pinkish-reds will be most reliable as test for color deficiency. These colors are being tested in the pilot models of the proposed Navy Lantern.

"Generalized recognition curves for the spectral colors are presented in the discussion section. Practical applications of the findings are given in a specific list of conclusions in regard to the selection of signal lights and to lantern tests for color deficiency. The project was conducted in cooperation with the Corning Glass Works."

INTERROGATION OF PROFESSOR G. VON STUDNITZ
at Beltane School, Wimbledon, on 8th April, 1946
Target Nos. C24/539, C9/837

British Intelligence Objectives Sub-Committee
Interrogation Report No. 70, 4 Sept., 46

Interest: Research on Structure of Retina (M of S, Gp. 1)

Retina:- a. Improvement of night vision.
b. Sensitivity increase in infra-red.
c. Restoration of normal colour vision.

"Professor G. von Studnitz was Director of the Department of Zoology in Halle University, a position he had held since 1936. He had conducted research into the structure of the retina with particular attention to the nature and function of the photochemical substances of the rods and cones. His work prior to the war was published (in 1940) in a textbook "Physiologie des Sehens". He had isolated biochemical substances from the rods and cones of retinae. The cone substance was further analyzed by chromatographic methods, into three substances which he claimed were the three colour sensitive pigments of the trichromatic theory. In addition he had identified the various photochemical products so isolated.

"In 1942 he was requested by the German Navy to seek methods of improving the night vision of naval personnel. He also carried out research into methods of increasing the sensitivity of the retina in the infra-red and into the possibility of restoring normal colour vision to those who were defective. The German Navy considered the improvement of night vision as the most important project of the three.

Improvement of Night Vision

"Two methods were explored:- (a) the administration of Vitamin A; (b) the administration of a compound akin to the photochemical substance extracted from the rods.

(a) Vitamin A

"Massive doses of the vitamin (40,000-250,000 units/day) were tried. Animal experiments on the absorption of the vitamin by the intestine showed that for effective absorption emulsification (with gum arabic) was necessary. Rod threshold measurements showed about a 15 fold improvement on laboratory workers. The findings were confirmed on a larger number of Naval personnel.

"Unemulsified vitamin A, used on a control group, failed to produce an improvement.

(b) Photochemical Substance of the Rods

"The precursor of the visual purple was believed to be Lutein a substance related to Xanthophyll. The preparation of this substance in an absorbable form proved most difficult and it was decided to use the Dipalmitic acid ester, Helenien, instead. The latter could be extracted in pure crystalline form from a species of marigold (Tagetes Patule Flore Pléno). About 55 gms. could be obtained from about 500 square metres of the crop. Emulsified preparations of the extract were given in doses of 200-600 milligrms. per day for about a week. An improvement in rod threshold resulted which reached a maximum in about 8 days and persisted for several weeks after withdrawal of the drug. Only rod threshold measurements were made, using the Novak Adaptometer, and amounted to a 10-15 fold improvement. No visual acuity determinations at low field brightnesses were made. It was also shown that the cone threshold, as measured on Comberg's Nyktometer (A Snellen test chart read at low brightness) was favourably affected.

"A quantity of Helenien was produced by I.G. Farben, Wuppertal and a large scale experiment on 400 naval personnel was carried out. Prof. v. Studnitz had not seen a report of this experiment but he had learned through a Dr. Hamburger, who was conducting the trials, that the results were "better" than the original laboratory tests (in which about half-a-dozen people were used). The production of the substance was extremely expensive and in 1945 v. Studnitz had been conducting animal experiments with a view to improving the absorption of the chemical. He had shown that after absorption the Helenien was stored selectively in the retina. The administration of the drug caused no noticeable ill-effects.

Infra-red Sensitisation

"Investigations had been conducted into the nature of the reaction products when the red sensitive substance of the cones was "bleached" by exposure to light. It was found that when the red photochemical substance was acted on by red light it gave rise to another substance whose absorption increased rapidly in the range 7500 A° - 10,000 A°. It was argued therefore that after exposure to red light the eye should possess an increased sensitivity to the deep red and infra-red (assuming that the increased photosensitivity of the bleaching product gave rise to a visual response). The bleaching product proved to be transient but it was discovered that the administration of Vitamin C tended to stabilize it.

"Subjective measurements of the brightness of a photometric field at 7500 A° against another at a shorter (red) wavelength showed that the brightness sensation at 7500 A° increased following preadaptation in red light. The optimum time of preadaptation was 2-5 minutes at a field brightness of about 50 candles/sq. foot. The effect normally lasted from 1-2 minutes but its persistence could be increased to 10-15 minutes by the administration of 150 mg. of Vitamin C per day. The effect was most pronounced about 6 hours after taking the vitamin.

"The precursor of the red substance of the cones proved to be Astaxanthine (prepared from lobster shells) and the administration of this in conjunction with Vitamin C materially increased the sensitivity of the eye in the deep red. Experiments of this nature were in progress at the end of the war and the results are still incomplete.

Improvement of Defective Colour Vision

"In addition to its being the precursor of the red photosensitive substance Helenien is also believed to be the precursor of the cone substance having its maximum response in the yellow green region of the spectrum and which is one of the three responsible for normal colour vision. Assuming that deuteranomalous trichromats suffer from a deficiency of this receptor substance, it appeared likely that administration of Helenien would produce an improvement. Three subjects were tried, measurements being carried out with a Nagel anomaloscope. In one subject a marked improvement resulted and significant changes were noted in the other two but not always in the direction of normality. By administration of the drug to a normal observer an excess of the yellow green pigment in the retina was produced which resulted in anomalous colour vision."

* * * * * * * * * *

INTERROGATION OF PROFESSOR SCHOBER
at Beltane School, Wimbledon, on 25th April, 1946
Target No. C9/932

British Intelligence Objectives Sub-Committee
Interrogation Report No. 136, 6 Sept. 1946

Interest: Research into Physiological Optics and Illumination (Gr. 2)

"Professor Herbert Schober worked at Technische Hochschule, Vienna from 1937-1939 when he transferred to Deutsche Seewarte, Hamburg, in which he remained until the end of the War. During this period he was concerned with a variety of problems in Physiological Optics and Illumination that arose in the German Navy, e.g., Night Vision, Glare, Night Myopia, Illumination of Instruments, etc.

Night Myopia

"His attention had been called to this problem by certain work carried out in Madrid University in 1943, (which has since been published in the Scientific press). He carried out both laboratory experiments and large scale sea trials in mine sweeping flotillas. In the laboratory experiments he conducted visual acuity tests at a brightness approximately equal to moonlight and found that a correction of -2D as compared with that required in full daylight gave maximum acuity. Such corrections were obtained using ordinary spectacle lenses.

"In the sea trials he had made a comparison of the day and night focus of binoculars and found that the latter was about 2D more negative than the former. At the close of the War he had recommended that binoculars at night should be set 2D more negative than by day. This procedure received favourable reports from mine sweeping flotillas.

"His work on this problem was incomplete at the end of the War and though he regarded the phenomenon of night myopia established as a fact, he was unable to give an explanation of it.

Night Vision

"He had carried out a limited number of experiments on the improvement of night vision by means of drugs. During certain sea trials he administered Vitamin A to a number of observers but the results were negative. He had since learned that Vitamin A should be administered in an emulsified form and he attributed his failure to this omission.

"In his laboratory experiments he had tried a hormone preparation, extracted from foxes, but with no marked success. He had tested night vision with a Novak Adaptometer (rod threshold instrument) and had also used the Comberg Adaptometer (cone threshold). He was unaware of the experiments initiated in the German Navy by Professor Studnitz of Halle University, on the improvement of night vision.

Magnification and exit pupil of hand-held binoculars

"No laboratory experiments on this problem were carried out but rather he concentrated on large scale experiments in Warships at night. He fitted various binoculars with stops over the object glasses to secure various sizes of exit pupil. He used marks painted on ships as targets for his experiments. He saw that each observer was corrected for night myopia before the start of an experiment. He used about 1,000 observers in the course of the investigation.

"As a result of these trials he found that it was definitely of advantage to have an exit pupil of 7 mms. diameter. He did not agree with Zeiss investigators who had stated that an exit pupil of 5 mms. was sufficient. As regards magnification as far as hand-held binoculars were concerned, it was not profitable because of the inherent unsteadiness of a hand-held instrument to increase the magnification beyond 8. In his opinion the best hand-held instrument was an 8 x 50.

Use of Red Light for Dark Adaptation

"Experiments had shown that good dark adaptation was achieved if an observer wore goggles containing Schott RG. 2 red glass 2 mms. thick for about 30 minutes before going into the dark. Schober remarked that the German surface Navy was slow to take advantage of this though he had recommended it for all bridge personnel. He regarded the blue lights used on bridge instruments as unsatisfactory. Instruments should be lit with red lamps which did not transmit at wavelengths shorter than 5800 A°. A trial of red lighting was being carried out on the PRINZ EUGEN in the latter part of 1944 but was not completed. The use of red goggles for dark adaptation was viewed more favourably by the submarine service.

Instrument Lighting

"As stated, Schober regarded blue lighting of instruments at night as unsatisfactory and advocated red. He had also investigated the use of radioactive (self-luminous) paint for the marking of instruments. He made comparisons between a black dial with markings filled with the luminous paint and a dial completely covered with luminous paint upon which the markings were painted in black. The latter method he found produced the least glare since it allowed of a lower brightness of paint being used with consequent reduction in radium content and diminution in injurious physiological effect. This method he stated helped to outline a submarine control room in the event of the failure of the lighting system. Such a scheme was difficult to use with small dials having closely spaced markings.

Classification of Optical Instruments by the measurement of the threshold of brightness difference and the transmission of factor.

"A special apparatus was used for this test. In an integrating sphere a small hole was drilled which could be made white or black (by placing behind it a black cavity). Opposite the hole was a collimating lens. The sphere was lighted to a brightness of about 10 foot lamberts. Measurements of the brightness of the

[redacted]

white and black spot without the instrument and through the instrument were made with a Pulfrich photometer. The former measurement gave the absorption in the instrument while the latter gave a value for the scatter in the optical system. The integrating sphere was used so that extraneous light entered the optical system from very wide angles as would happen under normal conditions of use. Thus the scattering coefficient so obtained took into account scatter from the walls and internal diaphragms which tended to reduce the clarity of the image. The method of testing is described in LIGHT, 1944.

"With this apparatus samples of telescopes and periscopes fresh from the manufacturers were tested and, in addition instruments returning from service at sea were investigated, often as the result of complaints from Naval Officers concerning the poor clarity of the image. In his experience increase in scatter was much more serious than loss in light transmission. The latter measurement alone he regarded as a poor criterion of performance.

Selection of observers for Stereoscopic instruments

"It was obvious that Schober had contributed nothing in this field, and had merely started to repeat investigations already carried out with apparatus of the three-pin type. He gave no evidence of having made any new approach to the problem."

J. Tunstead) Admiralty Research
C. T. Wright) Laboratory

[redacted]